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TUBULAR LUMINESCENCE LAMPS FOR GENERAL ILLUMINATION

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In connection with a general description of the principles and properties of tubular luminescence lamps printed earlier in this periodical, such lamps are here discussed which have been especially designed for use on the 220 volt mains. The most satisfactory dimensions of the lamps are derived from the maximum working voltage given, the desired light flux and an assumed limit for the brightness. Furthermore, after a brief description of the series apparatus the question of the colour of the lamps is carefully studied. Because of the great variety of tints which can be obtained by mixing different luminescent substances, it is important to know how the opportunities presented can best be exploited. The factors which here play a part are explained and illustrated with examples.

A light source of high efficiency can be obtained from the low-pressure mercury discharge which itself emits only little visible light and much ultraviolet radiation, when the ultraviolet radiation is converted into visible light by means of luminescent substances. The tubular luminescence lamps which have been constructed on this principle possess, in addition to their high efficiency, various other good qualities as well, which have already been discussed in this periodical [1]). The colour of the lamps exhibits practically no flicker, the light flux and the life of the lamps is much less dependent on mains voltage fluctuations than with the ordinary filament lamp. These properties give reason to expect that luminescence lamps will be widely used in the future.

In the article mentioned [1]) only one use of the lamp was described, namely for shops, restaurants, etc. where a large number of lamps in series are connected with a high-voltage transformer. This in many respects very simple and practical solution is naturally out of the question when luminescence lamps are to be used for more general purposes of illumination. In the home, for example, one or only a few lamps will generally be used at once, while moreover the use of high-voltage is impossible in many cases. Recourse must be had to the connection of each lamp with a separate series apparatus to the mains. This has certain consequences for the construction of the lamp which will be further considered in the following. At the same time the colour of the luminescence lamps will be discussed.

The construction of the lamp

The general construction of luminescence lamps has already been described in the article referred to [1]): The discharge takes place in a long glass tube on the inside wall of which the luminescent substances are deposited in powder form. The electrodes are in the shape of small spirals covered with a substance which emits electrons easily and which are kept at such a temperature by the bombardment by ions and electrons occurring in the discharge, that they are able to provide the electrons necessary to maintain the discharge. In the application previously described the length of the tubular lamps was 2 m (HTL 200), in the model for low voltage (TL 100), however, it has been reduced to 1 m with a tube diameter of 3.5 cm. This choice was made on the basis of the following considerations.

In order to make the lamp burn steadily at a mains voltage of 220 volts, it is found that the working voltage V_B may not be higher than about 120 volts [2]) —due partly to mains voltage fluctuations. The working voltage, aside from the voltage drop at the electrodes, is given roughly by the product of the gradient G (voltage per cm of the discharge-column) and the length l of the lamp. Now the gradient is mainly determined by the diameter d of the tube [3]), and the relation between G and d for a tube with the customary gas filling (mercury and argon) is given in *fig. 1*. If for V_B we assume a certain value, then from fig. 1 for each value of d the required length $l = V_B/G$ of the lamp follows. This length is plotted as a function of d in *fig. 2*, for different values of the parameter V_B. The point l, d for the lamp to be constructed must in every case lie below the line $V_B = 120$ volts.

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[1]) P. Schouwstra and G. Zecher, Tubular luminescence Lamps, Philips techn. Rev. 4, 337, 1939.

[2]) See: E. G. Dorgelo. Alternating-current circuits for discharge lamps, Philips techn. Rev. 2, 103, 1937.

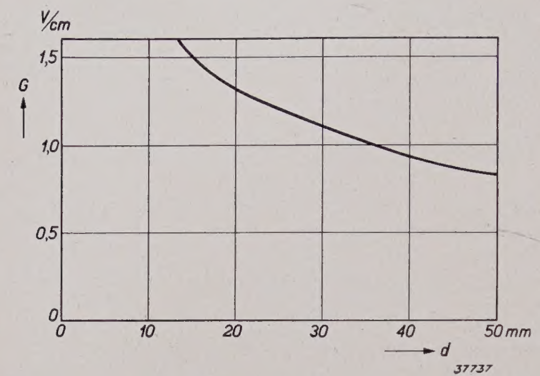

Fig. 1. Gradient G as a function of the diameter d of the discharge tube for the customary gas filling of the luminescence lamps (mercury + argon).

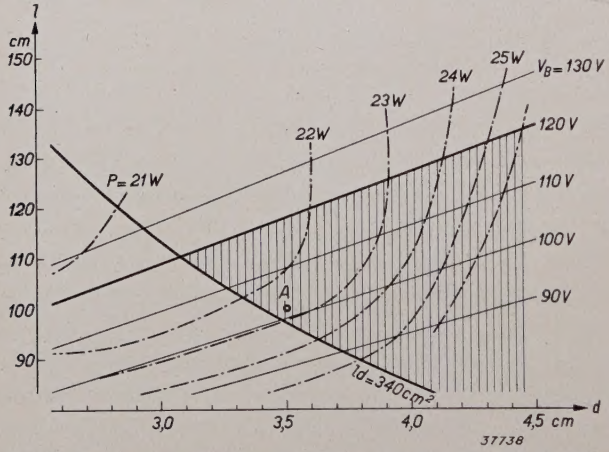

Fig. 2. The practically straight lines give the relation derived from fig. 1 between length l and diameter d of the tubular lamps for certain values of the working voltage V_B. The conditions $V_B<120$ volts and $B < 0.3$ c.p./cm² with a light flux $\Phi = 100$ decalumens limit the choice of dimensions for the tubes to the shaded area of the surface. The broken lines connect points at which for $\Phi = 100$ decalumens the same power P is needed. Point A gives the dimensions actually chosen.

A further limitation occurs due to the fact that on the one hand the lamp must give a certain minimum light flux — in our case this was fixed at $\Phi = 100$ decalumens —, while on the other hand it was considered desirable to choose such a low brightness that when the lamps were used without fittings no glare would be experienced from the direct light. With the high level of illumination to which one has become accustomed with modern lighting, even at the low height at which lamps are usually hung in private homes, it was found to be sufficient if the brightness B of the lamps was less than 0.3 cp/cm². For a tubular light source $\Phi = Bld\pi^2/10$. With $I = 100$ and $B<0.3$ it follows that $ld>340$ cm². If in fig. 2 we draw the line $ld = 340$, the point l, d to be chosen must lie to the right of this line.

The choice of the point l,d within the remaining shaded area of the surface is finally fixed by the desire to obtain as high an efficiency as possible. With a given light flux $\Phi = 100$ decalumens a certain light flux per metre tube length Φ/l corresponds to every point in fig. 2, and to this in turn a certain current i corresponds, which can be read off from the experimentally found group of curves in *fig. 3*. The variation of current and voltage of the discharge tubes with time is practically independent of the dimensions and the current, so that now for every point in fig. 2 the watt consumption P can be calculated from i and V_B as $P = 0.85\ iV_B$ (i and V_B are effective values). By connecting points with equal value of P, the curves indicated by broken lines in fig. 2 are obtained. From the shape of these it follows that the point l,d can best be chosen in the extreme left-hand corner of the shaded part. The most economical lamp which satisfies our requirements as to V_B, Φ and B would thus have a length of 110 cm and a diameter of 3.1 cm. The length has been altered to 1 m, to which a diameter of 3.5 cm corresponds. The current for this point, indicated in fig. 2 by A is 250 mA, the wattage consumption about 22.5 W, the light yield about 44 lm/W.

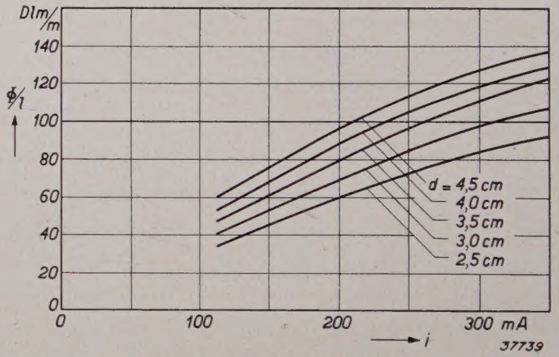

Fig. 3. Relation between the current i and the light flux obtained per metre length of tube (Φ/l) for different values of the diameter d of the tubes. The curves are valid for a definite composition of the luminescent layer (colour point I in fig. 9).

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[3]) To a certain degree the gradient still depends upon the current of the discharge, this influence is, however, neglected here for the sake of simplicity.

The series of curves of fig. 3 holds for a given composition of the luminescent layer in the tube. For other compositions of practical importance (other colours) the shape of the curves, and thus also that of the broken line curves in fig. 2, will be slightly different; the conclusion that the highest efficiency is obtained in the corner of the shaded area, however, remains valid. The most favourable dimensions for the lamp are therefore independent of the colour chosen.

The series apparatus

The series apparatus which is necessary to make the lamp burn steadily because of the negative characteristic of the gas discharge, consists in its simplest form of a choking coil. If we assume for this coil a reasonable consumption of about 5 W, the power factor at the above-mentioned values of the output and current in the lamp (22.5 W and 0.25 amp., respectively) is given by $\cos\varphi = (22.5 + 5)/0.25 \cdot 220 = 0.5$. In general therefore an improvement of the power factor will be desired in this case.

A point which requires special attention is the ignition. In the application previously described, where a high-voltage transformer was used, the no-load voltage of the transformer could easily be made so high that the tubes ignited under any circumstances. The mains voltage of 220 volts is, however, not immediately sufficient to cause breakdown in the gas of the tube. The ignition voltage must therefore be lowered by heating the hot cathodes of the lamp in advance, while in addition a voltage impulse is necessary. For this purpose the lamp is connected as in *fig. 4*. After the lamp is switched on with the main switch *l*, the auxiliary switch *2* is closed and a current of about 0.5 amp flows through the choke *L* and the two hot cathodes. These cathodes are of such dimensions that with this current they reach a sufficiently high temperature in about 1 sec. If the auxiliary switch is now opened, the self-induction causes a voltage impulse on the lamp whose magnitude depends not only upon the construction of the switch, etc. but also upon the phase of the alternating current at the moment of interruption. If this phase is by chance too unfavourable, the closing and opening of the auxiliary switch must be repeated.

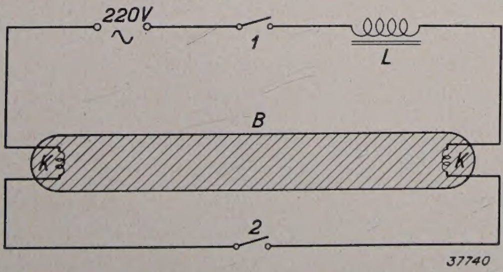

Fig. 4. Simplest connections of the luminescence lamps. *B* lamp, *L* choke, *K* hot cathodes, *1* main switch, *2* auxiliary switch for ignition.

The closing and opening of the auxiliary switch can take place automatically by constructing it in the form of a bimetallic switch of the type shown in *fig. 5*. The bimetallic strip *B* with the switch contact *C* forms one electrode of a small gas-discharge tube. When the mains voltage acts upon this due to the closing of the main switch (*l* in fig. 4) breakdown occurs in the tube, the bimetallic strip is heated by the discharge and, by bending, closes the contact *C*. The hot cathodes of the lamp are now heated. At the same time, however, the discharge in the small tube is short circuited, the bimetallic strip cools and the contact *C* is opened. If the lamp does not ignite the process is repeated until it does.

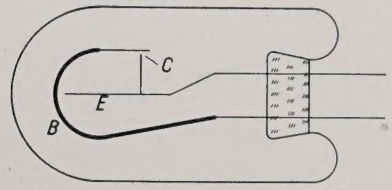

Fig. 5. Automatically working auxiliary switch for the connections in fig. 4. *B* bimetallic strip, *E* counter electrode, *C* switch contact. Between *B* and *E* a glow discharge occurs which heats the bimetallic strip.

The bimetallic switch may not of course break down when the lamp is ignited. The breakdown voltage of the switch tube must therefore be higher than the working voltage of the lamp and lower than the mains voltage. This can be realized by a suitable choice for the gas pressure in the small tube. The contact *C* and the other components must also be so constructed that the opening takes place abruptly enough to cause the desired voltage impulse.

In *fig. 6* a photograph is shown of the tubular lamp with a series apparatus consisting of choke and bimetallic switch.

Another method of connecting the lamp with the mains is with the use of a resonance connection such as is represented in *fig. 7*. If the self-induction *L* and the condenser *C* are in resonance at the mains frequency, then in every period a sufficiently high voltage acts on the lamp to cause it to ignite, especially when by means of suitable connections provision is made that upon switching on the hot cathodes are also heated. After ignition of the lamp it acts as a shunt on *C*, so that the resonance is disturbed. An advantage of the resonance connec-

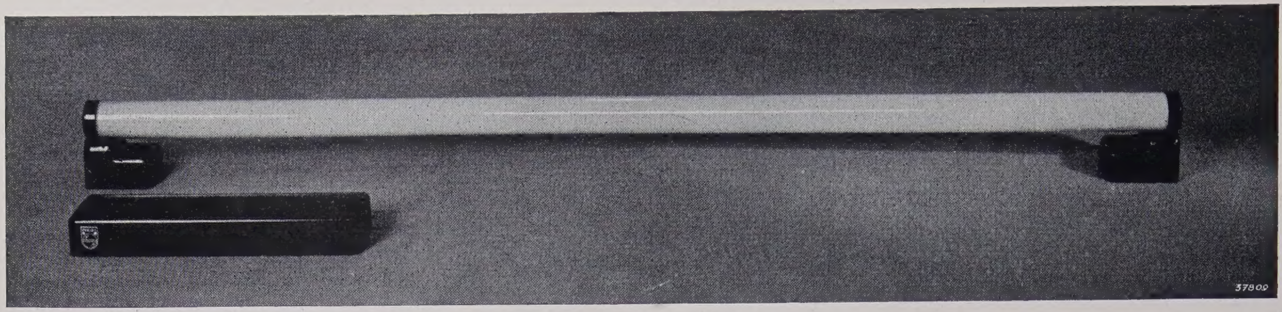

Fig. 6. Luminescence lamp TL 100 with series apparatus.

tions is that the lamp ignites almost immediately after being switched on, while, moreover, the connections can be so arranged that the power factor of the apparatus with the lamp burning is practically unity.

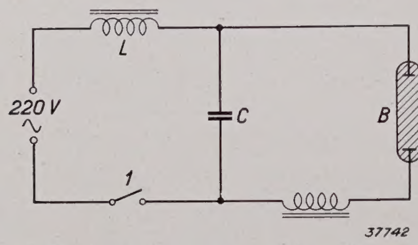

Fig. 7. Example of a resonance connection. The circuit formed by the choke L and the condenser C is tuned to the mains frequency.

The colour of the luminescence lamps

General considerations

One of the most important advantages of the luminescence lamp is the large degree of freedom it offers in the choice of the spectral composition of the light emitted, because of the possibility of mixing different luminescent powders (phosphors) in any desired proportion. In *fig. 8* the spectral energy distribution is given of the light of three of the most commonly used phosphors, namely of cadmium borate (red), willemite (green) and magnesium tungstate (blue). These colours are represented in the colour triangle of *fig. 9* by the points C, W, M. By mixing the three substances all the colours within the shaded triangle can be realized with an efficiency in the most favourable case (at point W) of about 70 lm/W, in the least favourable case (at point C or M) of about 35 lm/W [4].

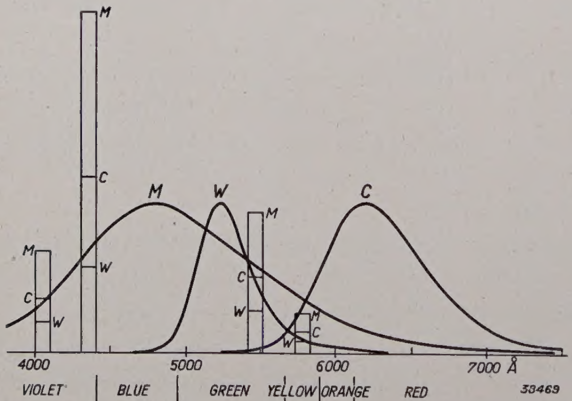

Fig. 8. Spectral energy distribution of the luminescence of cadmium borate (C), willemite (W) and magnesium tungstate (M). With the thickness of layer which gives the highest efficiency the visible mercury radiation simultaneously emitted by the lamps amounts to 10, 5 and 10 per cent, respectively, of the total radiation. The mercury lines are drawn exaggeratedly wide and of such a height that the area of the surface is a measure of the relative energy contribution at the thickness of layer mentioned. The ordinates for C, W and M stand in the correct relation for the case where the same total light flux is always produced. (The same holds for figs. 11*a* and 12*a*).

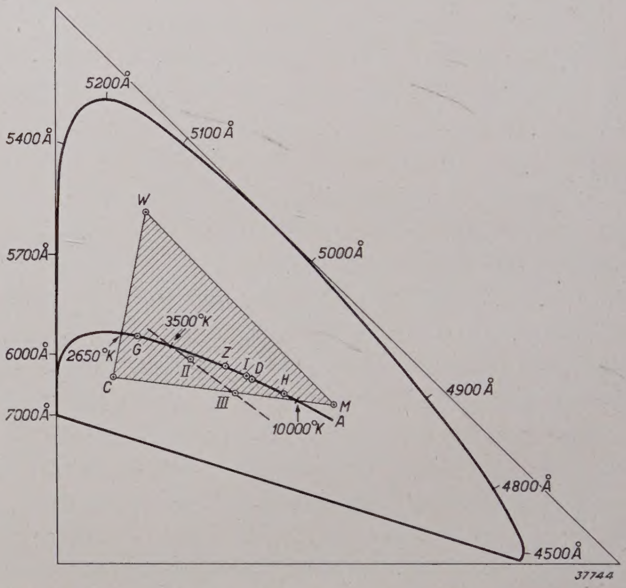

Fig. 9. Colour triangle. C, W, M are the colour points of the three phosphors calculated from the curves of fig. 8. By mixing the phosphors any colour point within the shaded triangle can be obtained, with an efficiency between 70 lm/W (at point W) and 35 lm/W (at C and M). On line A lie the colour points of black bodies at different temperatures (colour temperature). In addition the colour points are indicated of: gas-filled electric lamp G, sunlight Z, average daylight D, blue light of the sky H, and three kinds of luminescence lamps, I, II, III.

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[4] In the determination of the colour points for the three phosphors the fact must be taken into account that it is not exclusively luminescence light which is radiated by the tubular lamp, but that there is always a certain small proportion of mercury light. This proportion depends upon the thickness of the luminescent layer, which at the same

For the sake of comparison in fig. 9 the line A is also drawn upon which lie the colour points for glowing black bodies at different temperatures. Sunlight lies on this line (at point Z) with a colour temperature of about 5 000 °K (*i.e.* its colour corresponds to that of the radiation of a black body at about 5 000 °K), and furthermore so-called average daylight (the light when the sky is completely overcast), (point D) with a colour temperature of about 6 000 °K, the light of the blue sky H with a colour temperature of about 8 000 °K and an ordinary gas-filled electric lamp of for instance 220 volts, 500 W, point G, with a colour temperature of 2 850 °K. By using filaments at different temperatures other points on line A could also be realized with the electric lamp; at points to the right of G, however, their life would be short and to the left of G their efficiency, which at G itself may be about 16.5 lm/W, decreases rapidly. This is also the case when one attempts to reach points to the right of G with a filament at normal temperature combined with filters, for instance in the form of a coloured bulb; the Philips "sunlight lamp" which is constructed on this principle and whose colour temperature is about 4 200 °K, has for instance only half the efficiency of a normal gas-filled lamp.

How can we make the best use of the great freedom in the choice of colour of the luminescence lamps?

Considering the fact that according to fig. 9 all colour temperatures between 2 500 and 10 000 °K can be obtained by a suitable mixing of the phosphors, an obvious solution would be to use the luminescence light with its excellent efficiency to replace or supplement daylight or electric light. In doing this, however, various factors must be taken into account.

In the first place at a given level of illumination it is found that the colour temperature must lie within certain limits if the effect of the illumination is to be pleasing. Roughly, it may be said that a low or a high colour temperature corresponds to a low or a high level of illumination, respectively. We have investigated this relation experimentally somewhat more closely by introducing in a room a variable number of electric lamps whose current (*i.e.* the temperature of the filaments) could be varied. The result is given in *fig. 10,* while in the text below the figure the experiments are described. Below the lowest curve the illumination is "dim" (at low colour temperature) or "cold" (at high colour temperature). Above the highest curve the unnatural colour reproduction was unpleasant. These obviously vague limits within which the illumination is considered "pleasing" could in our experiments be determined at least with an accuracy of 20 or 30 per cent.

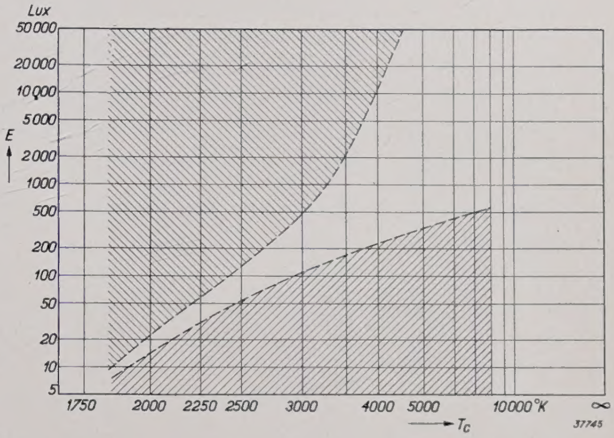

Fig. 10. For every colour temperature there exists a highest and a lowest level of illumination at which the illumination is considered "pleasing": at lower levels the illumination appears dim or cold, at higher levels the colour rendering is unnatural. The left-hand part of the limiting curves, up to a colour temperature of 2 850 °K, is recorded by allowing electric lamps with variable (decreased) current to burn in a room, and varying the number of lamps. The illumination intensity on a table 80 cm high was here measured. In the right-hand part the lowest level which does not give the impression of coldness was determined by experiments with daylight itself and with the daylight luminescence lamps to be described below. The shape of the upper curve has been extrapolated in this region with the help of the fact that in direct sunlight (colour temperature 5 000 °K) even with the highest illumination intensities occurring (10^4 or 10^5 lux) the colour rendering is never found "unnatural". On the abscissa the reciprocal value of the colour temperature T_c is plotted, on the ordinate the logarithm of the illumination intensity E, since $1/T_c$ and $\log E$ are measures of the physiological estimation of these quantities. In these coordinates the lower limiting curve takes on a nearly linear form. It may be mentioned that the experiments were carried out in a laboratory room. It was found, however, that in a living room with light-coloured furniture and wall coverings roughly the same limits are obtained.

From fig. 10 various conclusions may be drawn. If for interior illumination an approach to daylight is desired by the use of luminescence lamps with high colour temperatures, then according to the curve at a colour temperature of 4 000 °K an illumination intensity of at least 240 lux must be used (see the text under fig. 10 for the significance of these figures), at 7 000 °K at least 500 lux. Since the level of illumination is already determined by other considerations the colour temperature cannot be chosen arbitrarily high; if in a living room, for example, one does not wish to use more than 150

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time determines the efficiency. In each case a thickness of the layer is assumed such that the highest possible efficiency is obtained; the percentages of mercury light hereby occurring for the three phosphors are indicated in fig. 8, and from the spectral composition of the total radiation the three colour points are then calculated. On the general subject of the colour triangle see for example Philips techn. Rev. 1, 282, 1936 and 2, 39, 1937.

lux, then according to the figure 3 500 °K is the upper limit for the colour temperature.

A further limitation occurs in the special case where the new light source must be capable of being **combined** with that already existing, namely with daylight or electric light. The kinds of light to be combined will then have to have approximately the same colour (the same colour temperature), or at least they must exhibit no unpleasant contrast of colour. But in addition the **colour rendering** obtained with the different light sources must also not be too different. Similarity of colour by no means ensures similarity of colour rendering, since the latter is determined by the spectral composition of the light and the same colour point in the colour triangle can be obtained with quite different spectral compositions. The colour rendering will be dealt with in more detail below.

While until now we have only considered cases in which the luminescence lamps were to be used for imitating or in combination with radiations on the line *A* in fig. 9, the question may now be put as to whether luminescence lamps may not also be considered which have colour points in other parts of the shaded triangle. The question whether such a choice of the colour point can have special **advantages** we shall leave open [5]).

It is indeed found that a fairly large deviation from line *A* is permissible if the following points are borne in mind. In the first place there is the seemingly paradoxical requirement that the light must not appear definitely coloured. Upon direct comparison of course all kinds of light appear in general coloured. If, however, there is no possibility of comparison, daylight and electric light do not appear coloured but "relatively white", and this is also true for kinds of light with colour points not on line *A* as long as the deviations are not too great.

The second requirement concerns the colour rendering. While the colour rendering can be judged by **comparison** when luminescence is used in combination with other light and the designation of the colour impression obtained and the saturation of the colour obtained must agree, when only luminescence lamps are used no comparison is possible. In judging the colour rendering therefore in this case one must have recourse to "colour memory" which is chiefly confined only to the **designation** of colours. Care must therefore be taken that the classification of the shades of colour of the objects in our environment in the light of the luminescence lamps does not become unnatural, *i.e.* does not deviate too much from that in daylight.

In the third place there is now also a limitation of the colour temperature in connection with the intensity of illumination used. At colour points which do not lie on the line of black bodies we may not indeed speak of a colour temperature. Nevertheless as experiments by **Judd** [6]) have shown we can "assign" colour temperatures to such points without ambiguity; this temperature is then that at which a black body exhibits the smallest possible colour difference with the kind of light under consideration. Experiments have shown that fig. 10, at least as far as the lower limiting line is concerned, also gives useful results for assigned colour temperatures.

Examples

We shall now illustrate the way in which the results obtained can be put into practical use.

As first example we shall consider a lamp which can be used specially for supplementation or taking the place of daylight. Since the colour temperature of daylight varies between about 5 000 and 8 000 °K, according as one is concerned with direct sunlight or with the light of a more or less overcast sky, the colour temperature of the lamp must be chosen between about 5 500 and 7 000 °K if it is not to exhibit a large colour difference with sunlight. In order not to be compelled to use too high illumination intensities when the lamp is used alone, the colour temperature should not be chosen higher than 5 500 °K. The colour point of this lamp then lies at *I* in fig. 9. The spectral energy distribution of the light which is obtained with the mixture of the three phosphors corresponding to this is shown in *fig. 11a*. In *table I* the composition of the light is indicated according to the block method [7]) often used in this periodical; the whole spectrum is hereby divided into eight wave length regions (blocks), whose proportions of the total light radiation are measured or calculated. A comparison with the figures for average daylight given in the same table shows that a good agreement in the colour rendering with the two kinds of light can also be expected. This was tested experimentally with the help of the colour cards of **Ostwald**'s colour atlas, in three steps. First the brightness of the cards in

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[5]) We confine ourselves here expressly to normal interior illumination. It is unnecessary to state that special effects, for instance for advertising purposes, can be obtained by deviation from line *A*.

[6]) D. B. **Judd**, J. Opt. Soc. Amer. **26**, 421, 1936.

[7]) See for example Philips techn. Rev. **4**, 66, 1939.

Table I

Distribution of the light of different light sources over the eight blocks of the spectrum indicated

	4 000	1	4 200	2	4 400	3	4 600	4	5 100	5	5 600	6	6 100	7	6 600	8	7 200
Lamp *I*		0.016		0.432		0.638		9.3		42.9		36.8		9.43		0.363	
Daylight		0.027		0.228		0.801		10.8		40.8		36.3		10.3		0.73	
Lamp *II*		0.010		0.409		0.224		4.06		38.4		43.4		13.0		0.471	
Electric lamp		0.005		0.060		0.249		5.47		33.4		42.6		16.7		1.57	
Lamp *III*		0.012		0.475		0.462		7.25		35.0		38.1		18.0		0.695	

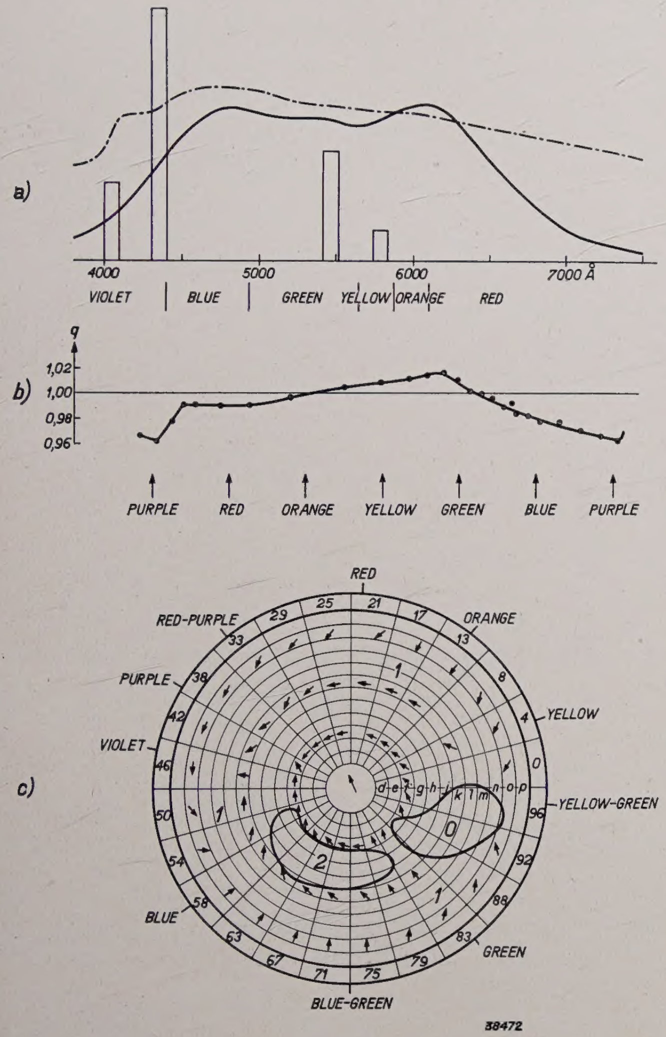

Fig. 11. *a*) Spectral energy distribution of the radiation of a luminescence lamp in which the three phosphors *C*, *W*, *M* are so mixed that the colour point *I* in fig. 9 is obtained. The broken line curve is for average daylight.

b) A coloured card upon illumination with average daylight in general exhibits a different brightness than upon equally intense illumination with the luminescence lamp *I*. For 24 colour cards of the *nc* series of Ostwald's colour atlas, of the colours given along the abscissa, the ratio *q* between the two brightnesses measured is plotted. At all points *q* lies so close to 1 that the differences are practically unnoticeable.

c) A complete set of colour cards (*c*-set) which was first observed in daylight and then in the light of lamp *I*. Each compartment represents one card. The colours are designated around the circumference of the circle (numbered 0-96); from the centre toward the outside the saturation increases (letters *d* to *p*). The arrows indicate the colour shifts observed. Only in the region marked "2" are such shifts clearly observable.

the two kinds of light to be compared was determined from the spectral variation of the coefficient of reflection of the cards and from the spectral distribution of intensity of the two kinds of light. For a number of cards (of the *nc* series) the ratio of the two brightnesses calculated is plotted in fig. 11*b*. It may be seen that this ratio does not deviate very much from unity for any of the cards. As second step the shade of colour and saturation were investigated for a series of cards by illuminating one half of each card with the luminescence light and the other half with average daylight [8]). The difference in colour between the two halves was designated by 0 (not appreciable), 1 (just appreciable), 2 (clearly appreciable), 3 (very striking, quite different colour). From the results given in fig. 11*c* it may be seen that the differences are almost everywhere limited to "1"; there is only a very small region with differences of the order of "2", while differences "3" do not occur. Most colours are somewhat less saturated in luminescence light than in daylight. Finally as third step, experiments were carried out in which the colour rendering was judged exclusively by colour memory: the colour cards of the series mentioned were illuminated with the lamp and an attempt was made to name the colours observed as accurately as possible. The differences occurring with respect to the naming of the colours observed in daylight were found to be slight and in satisfactory agreement with the diagram in fig. 11*c*.

Summarizing it may therefore be stated that the luminescence lamp with the colour point *I*, both in respect to its colour and in respect to its colour rendering, very closely approaches average daylight and may be used not only to replace but also to supplement the latter.

If the emphasis lies more in the supplementation than in the substitution, then it is not actually necessary to try to approach average daylight so closely. A supplementation of daylight will in practice be necessary chiefly during the last few hours before sunset, at which time the colour temperature of daylight, expecially with overcast sky generally lies lower [9]) than the average value (the light is redder). The colour temperature of the lamps may thus be chosen somewhat lower.

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[8]) This method has already been described by P. J. Bouma, Colour reproduction in the use of different sources of "white" light, Philips techn. Rev. **2**, 1, 1937.

In the second example which we shall discuss it was mainly a question of low levels of illumination. For reading and other work an illumination intensity of 150 to 250 lux is often applied. According to fig. 10 the colour temperature must then lie between about 2 550 and 4 100 °K. The lower limit mentioned corresponds to a colour point in the colour triangle of fig. 9 which is obtained by mixing practically only cadmium borate and willemite (line *C-W*). A glance at the spectral distribution in fig. 8 shows that the light so obtained will contain practically no blue or violet except what is present in the mercury light (line 4 358 Å). It may therefore be expected that the colour rendering by a lamp with such a low colour temperature will not be satisfactory. It is thus better to choose for the purpose in view a colour temperature closer to the upper limit, 3 500 °K, for example, where the content of blue in the light of the magnesium tungstate improves the colour rendering. Further improvement can still be attained by deviating slightly from the line *A* for black bodies and adopting colour points with the assigned (see above) colour temperature of 3 500 °K. These points all lie on the dotted straight line of fig. 9, and the point to be chosen on this line is indicated by *II*. *Fig. 12a* shows the spectral energy distribution of the light of this lamp, while in table I the block division is given. For the sake of comparison the spectral distribution of intensity of the electric filament lamp is also given here. The colour rendering of lamp *II* has been investigated in the same way as described above, and primarily by colour memory. Only in the orange region were there are appreciable differences from daylight. The differences lie, however, in the same direction as those which occur upon illumination by ordinary electric light, to which we are already accustomed. A direct comparision of the colour rendering of lamp *II* with that of the electric lamp produced quite considerable differences, see fig. 12*b*. As was to be expected the colour rendering of lamp *II* is more nearly like that of daylight. In spite of this difference and the difference in the colour of the light itself from that of the ordinary electric lamp, the effect obtained upon combination of these two kinds of light is not found to be too unpleasant. As far as the difference in colour of the light is concerned this is because of the fact that the line joining the points *II* and *G* is practically parallel to line *A*; it is a well known phenomenon that such a difference in colour (blue-yellow contrast) is experienced as much less unpleasant than the difference in colour between two points whose connecting line is about perpendicular to line *A* (red-green contrast).

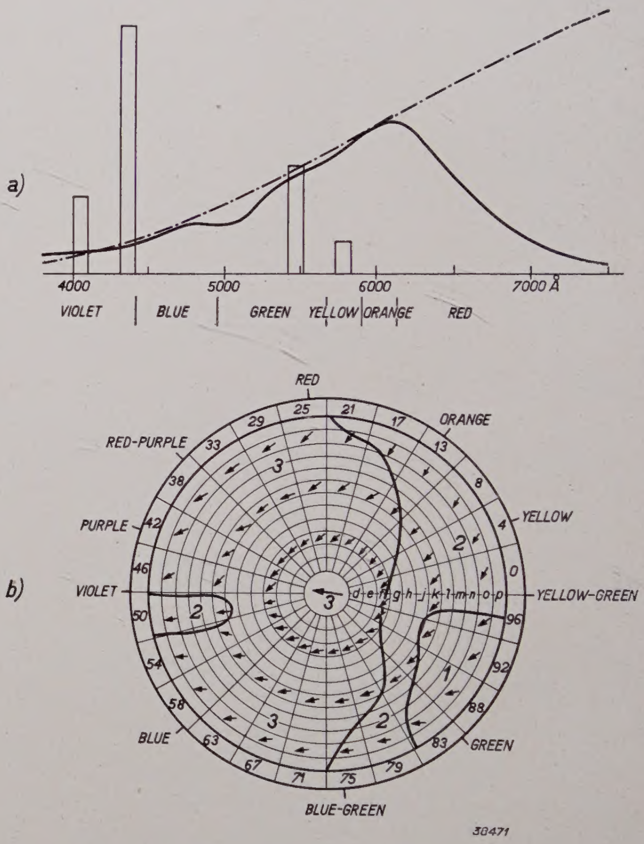

Fig. 12. *a*) Spectral energy distribution for luminescence lamp with colour point *II* in fig. 9. The broken line curve refers to ordinary electric light.

b) Colour shifts of the colour cards upon illumination first with electric light, then with lamp *II*.

Finally an example may be given in which use was made of the possibility discussed above of using colour points which are fairly far away from the line for black bodies. The advantage of such a light source may consist in a modification of the colour rendering in the sense that the colours of all objects appear more saturated, so that the whole interior under this illumination makes a fresher and brighter impression. A similar effect can be obtained for instance with the ordinary electric lamp by decreasing the energy contribution of the block 5 600—6 100 Å by means of a filter of

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[9]) See S. S. Ornstein, J. G. Eymers, D. Vermeulen and G. W. Postma, Daylight measurements in Utrecht, Proc. Kon. Akad. Wet. Amsterdam **16**, 1—79, 1936.

"Philiphane" glass[10]). By daylight a similar effect is produced when the energy contributions of the blocks 5 100—5 600 and 5 600—6 100 Å are both decreased. With a certain mixture of phosphors (colour point *III* in fig. 9) a spectral energy distribution with such a minimum in the wave length region in question can be obtained, see *fig. 13.* The lamps constructed with this mixture also actually produced for many colours the effect of the increase in saturation. The condition that the lamp itself must still appear "relatively white" is here no longer satisfied. The impression of being coloured is, however, still very weak, and in connection with the special applications of this lamp it is not serious. The colour rendering must in this case be judged exclusively by colour memory, since the lamp is not intended for use in combination with other sources of light. The designations of the colours found deviate here also only little from those by daylight.

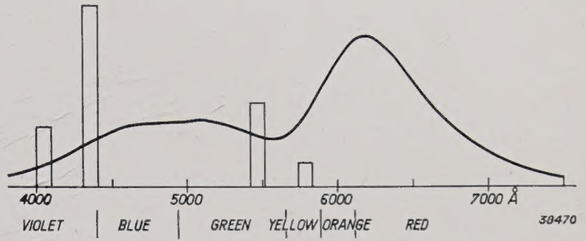

Fig. 13. Spectral energy distribution for the luminescence lamp with the colour point *III* in fig. 9.

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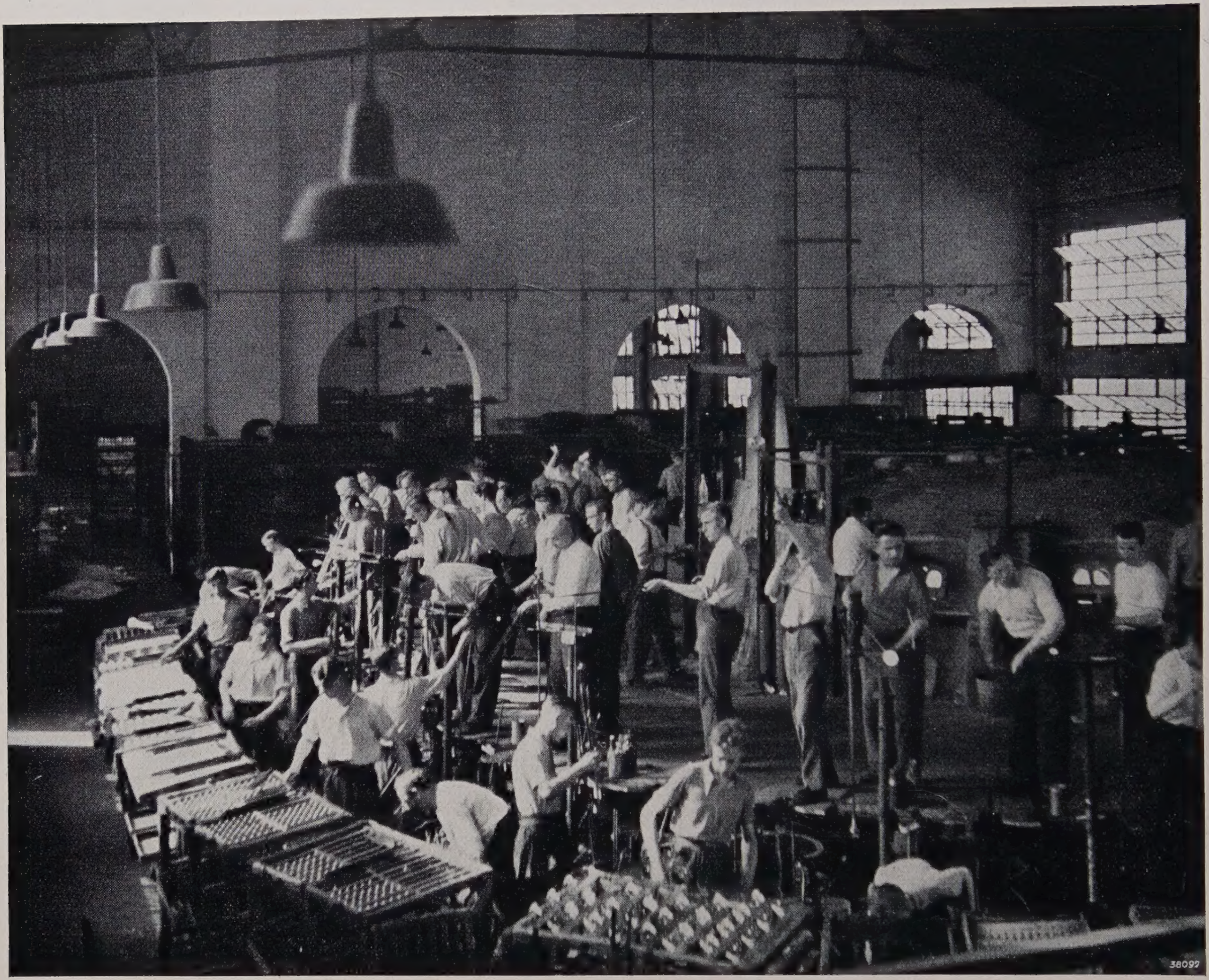
[10]) P. J. Bouma, The colour reproduction of electric lamps and "Philiphane" glass, Philips techn. Rev. **3**, 46, 1938. It may be pointed out that in this discussion the term "saturation" must not be taken in a physical but in a physiological sense; a colour gives the impression of being more saturated according as the colour point is farther away from the colour point of the light used.

VIEW OF ONE OF THE HALLS OF THE PHILIPS GLASS FACTORY

At the beginning of this year the glass factory had been in existence for 25 years.



While the manufacture of the bulbs for ordinary electric lamps and radio valves is at present mechanical, the blowing of bulbs for the many kinds of special lamps is still one of the branches of the industry where the old handicraft has been retained. The glass blowers stand in a ring around the glass furnace in which are situated the pots of molten glass. They take out portions of glass on the long pipes and blow it into the desired shape. The pipe with the still hot bulb is then handed over to the boys who form a second ring around the glass blowers, and who knock off the bulbs and place them in the racks. The picturesque impression which is given by the whole does not detract from the great efficiency and precision with which the work is actually done.

A SIMPLE APPARATUS FOR COUNTING ELECTRONS

by A. BOUWERS and F. A. HEIJN.

539.16.08

For the measurement of electron beams or of γ-rays an electron counter is usually used which contains as its most important component a gas-discharge tube fed with a D.C. voltage of about 1 000 volts which gives a current impulse for every electron entering (Geiger counter). After a brief explanation of the general construction of counting tubes and the connections in which they are used, a simple counter is described which is especially intended for use in demonstrations, for orienting measurements and the like. In contrast to precision counters which are manufactured by Philips for scientific purposes, in the apparatus described here emphasis has been laid upon obtaining a unit which is simple in operation and easy to transport. This has been made possible partly by the application of a cascade connection consisting of small condensers and selenium valves for exciting the necessary D.C. voltage.

The processes which take place in the nuclei of atoms are often manifested by some kind of radiation which accompanies them. The classic example is the spontaneous decomposition of radium in which not only electromagnetic waves (γ-rays) are emitted, but also material particles (electrons or β-rays and helium nuclei or α-rays). The experimental investigation of such processes indeed amounts chiefly to the detection and measurement of the radiations emitted.

The methods developed for this purpose have already reached a high degree of perfection. For example, with the help of the Wilson chamber and a magnetic field it is possible to determine the velocity of emitted electrons with great accuracy. With ionization chambers and amplifiers extremely accurate measurements have been carried out on the range of heavy particles (hydrogen nuclei for example).

In many cases, however, it is not a question of carrying out such precision measurements. For demonstrations during lectures, etc. and for orientating tests an instrument will suffice with which the presence of the radiation alone can be shown, and its intensity estimated if desired, while in these cases it is of more importance to make the apparatus as simple as possible and preferably easy to transport.

In this article an instrument will be described for the detection — the "counting" — of electrons, which has been especially developed for the use mentioned. For a better understanding it is desirable that something should first be said about electron counters in general.

Principle of the electron counter

For detecting an electronic radiation use is ordinarily made of the Geiger counter. This is a gas-discharge tube with a certain electrode configuration which can for instance be connected as indicated in *fig. 1*. A D.C. voltage slightly higher than the normal breakdown voltage is applied to the tube. Breakdown only occurs, however, when in the gas of the tube there is a "germ" in the form of a free electron. On its way to the anode this electron will ionize a number of atoms; each of the electrons freed in this way repeats the process and an avalanche of electrons ensues which initiates an independent discharge. With a suitable shape of tube and a sufficiently large resistance R in fig. 1, however, the discharge is found to be unstable: it breaks off after a very short time, after which the entire phenomenon can be repeated with a new "germ". The germs may now be provided by an electronic radiation which enters the discharge tube (counting tube) from the outside. An electron then manifests itself by a short current impulse through the tube which may be observed and "counted" with an electrometer as indicated in fig. 1.

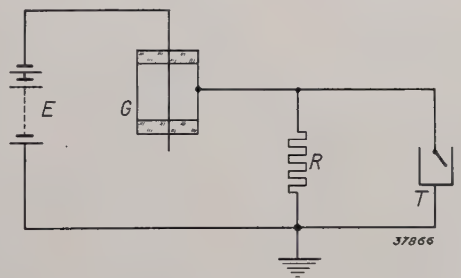


Fig. 1. Simple connections for the Geiger counter. G counting tube, R resistance of at least 10^9 ohms, E D.C. voltage source for 1 200 volts, T electrometer or other instrument for recording the current impulses.

A suitable electrode configuration for the counting tube has been found to be a cylindrical cathode along whose axis a fine wire is stretched as anode. The gas pressure is made several cm Hg, the voltage 900 to 1 200 volts. For the rest, different investigators have given very different (sometimes contradictory) specifications about the nature of the gas to be chosen, the materials of the electrodes, etc. This lack of agreement is a reflection of the fact that no explanation satisfactory in every respect has yet been found for the mechanism of the phenomena occurring in the counting tube, in particular for the breaking off of the discharge [1]). For this breaking off it seems to be essential that the current which begins to flow after the breakdown in the tube should not exceed a certain very low value. The current which increases rapidly upon breakdown causes a rapidly increasing voltage drop along the resistance R, so that the voltage on the tube falls. If R is larger, then already at a very small current the voltage loss becomes several hundred volts, with the result that the current does not exceed the above-mentioned critical value and the discharge is extinguished.

In the simple connections sketched in fig. 1 R must be at least of the order of magnitude of 10^9 ohms to obtain the desired effect. This results in very high requirements, which are difficult to satisfy in practice, being made of the insulation of the electrodes and connections; the insulation resistance must of course be greater than R, since it is in parallel with it. Another disadvantage of the high value of R is the following. If two electrons enter the counting tube in quick succession, the second electron will only cause a separate current impulse when the counter has already "forgotten" the impulse due to the first electron, *i.e.* when it has returned to its initial state. This takes a certain time, and this time is largely determined by the speed with which the voltage on the tube rises to the original value after the breaking off of the discharge. The RC time of the current circuit provided a measure of this. If we take for the capacity C of the counting tube and connections a value of 10 $\mu\mu$F — in practice one can scarcely reach a much lower value —, then at $R = 10^9$ ohms the RC time is 10^{-2} sec. This is therefore approximately the limit of the "resolving power" of the counter, *i.e.* two electrons which enter the counting tube within a time interval of less than 10^{-2} sec are counted as a single electron. The resolving power is obviously lower, the larger the value of R.

Considerable improvement with respect to the required magnitude of R is obtained by means of the connections indicated in *fig. 2* [2]). The voltage on R is applied to the grid of an amplifier valve which in the normal state passes no anode current due to a sufficiently strong negative grid bias. With a very small voltage on R, caused by the ignition of the counting tube, a large anode current begins to flow, which causes such a voltage drop along the anode resistance R_0 that the tube is extinguished. In order to bring about the extinction in the same way as in the connection of fig. 1 (*i.e.* at the same value of the current through the tube) the resistance R need now be only about 10^7 ohms, with $R_0 \approx 10^6$ ohms. Then a normal insulation of the electrodes and connections suffices, while the resolving power of the counter has become one hundred times as great.

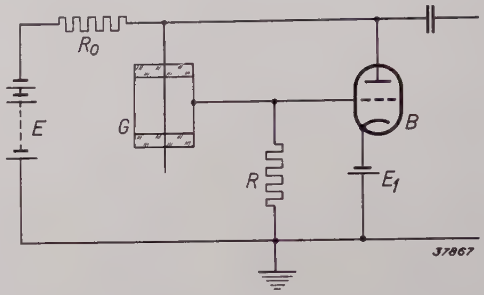


Fig. 2. Connections according to Neher and Harper. The voltage on R is amplified by an amplifier valve B. The resistance R here needs only to be 10^7 ohms, the anode resistance R_0 much less still. The D.C. voltage source E_1 provides the necessary grid bias.

We must stop a moment at the last point. Besides the counting tube and the connections belonging to it, the apparatus also contains an indicating instrument, for which as the simplest possibility we have assumed an electrometer in the above. Instead of this an instrument is usually used which automatically records the number of current impulses received, namely the familiar call counter of telephone technique. It is clear that the resulting power of the electrometer or call counter is always fairly limited, due to their mechanical inertia. In general it is much less than 100 per second. And since it is true here also that the slowest ship determines the speed of the whole fleet, it would be useless to increase the resolving power of the counter connections as much as possible without at the same time arranging the indication on the same basis. This can be done with the help of an automatic counting circuit ("scale of two" [3])) which transmits only every second current impulse of the counting tube to the call counter or to a second, third, ... counting circuit which works in the same way. By carrying out the counting in four stages, for instance, only every 16th electron is recorded in the call counter, so that it can handle 16 times as many electrons per second as its mechanical inertia would permit.

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[1]) A survey of a number of important publications on this subject is given by J. H. Gisolf: Elektronentellers, Ned. T. Natuurk. **4**, 129, 1937.

[2]) H. V. Neher and W. W. Harper, Phys. Rev. **49**, 940, 1936.

[3]) The first arrangement designed for this purpose was announced by C. E. Wynn-Williams, Proc. Roy. Soc. **A 136**, 312, 1932.

Electron counters with such counting circuits, which are indispensable for precise investigations, are also manufactured by Philips. Of the apparatus here described, however, an especially high resolving power was not required. The connections of fig. 2 were therefore used which make all the special precautions as to insulation superfluous (keeping the air dry, etc.), no counting circuit is used, however, in order not to make the apparatus unnecessarily complicated and heavy. We shall now study the apparatus itself in somewhat more detail.

Description of the apparatus

The counting tube

The most important structural data of the counting tube have already been mentioned above, while it was also stated that in certain respects, especially with regard to the material of the electrodes and the gas filling, opinions as to the best choice are quite divergent. A series of investigations on these points have been carried out in this laboratory [4]), and finally led to the result that the choice of the electrode material and of the gas are not so important as was previously thought, if care is taken to secure the greatest possible purity. This means among other things that the anode wire and the walls of the counting tube may not contain any adsorbed impurities which could be liberated when the tube is in action. The counting tube must therefore be carefully heated and degassed before it is filled with the desired gas (a mixture of argon and nitrogen, for example) and sealed off, just as is done with transmitter valves, X-ray tubes, etc. In the case of the counting tubes here developed, just as in that of the Philips transmitter valves and X-ray tubes, this is made possible by the use of chrome-iron: by making the cylindrical cathode of this material it is possible to weld a glass tube to both ends of it to support a tungsten wire serving as anode. The welds are vacuum-tight and heat-resistant. The construction can clearly be seen in the X-ray photograph *fig. 3.* The cathode cylinder is made so thin (about 0.1 mm) that electrons with very low speeds can still pass through it. The 0.1 mm thick anode wire is heated during the degassing by the passage of a current. In order to keep the wire tightly stretched during this process and later also (it must lie along the axis of the cathode cylinder) the spring visible in fig. 3 on the left is introduced.

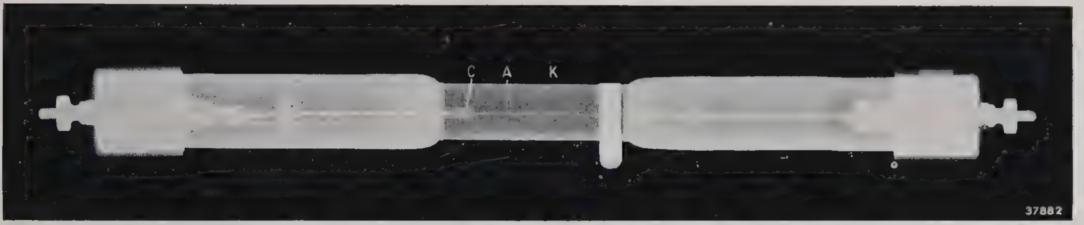

Fig. 3. X-ray photograph of the counting tube. At both ends of the thin-walled chrome-iron cathode cylinder *K* a tube of good insulating potassium-free glass is welded. The spring visible on the left keeps the thin tungsten wire *A*, serving as anode, tightly stretched. The shielding tubes *C* serve to improve the shape of the electric field in the tube.

It is interesting to note that the glass used for the counting tube may contain no potassium, since this element exhibits a natural, although very weak, radioactivity, and the electrons emitted would continually give rise to current impulses. Another cause of these undesired current impulses is the cosmic radiation which is present everywhere in space. Since the number of impulses occurring due to this cause is proportional to the volume of the counting tube, the tube has been made fairly short for our apparatus. (Conversely, the counting tubes which are made by Philips especially for investigating cosmic rays are very large).

The quality of a counting tube can be judged by means of the so-called count characteristic which indicates how many electrons the tube counts at different voltages when a given radiation, *i.e.* a given number of electrons per minute, is allowed to enter it. At very low voltage (too low for the occurrence of electron avalanches) the tube will obviously show no reaction; at very high voltage the fall in voltage caused by the resistance *R* will not be able to cause extinction, and a continuous discharge will therefore occur. Between these two extremes lies a more or less sharply-defined voltage region, the "counting region", within which the tube gives a number of current impulses proportional to the number of electrons entering it. The wider the counting region the better the counting tube. In *fig. 4* a characteristic is given of the counting tubes here described. It may be seen that, with the radiation used for recording, the voltage may lie between about 1 000 and 1 150 volts. With more intense radiation the counting region is smaller.

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[4]) W. de Groot and J. H. Gisolf, Ned. T. Natuurk. **3**, 161, 1936; J. H. Gisolf, Physica **4**, 69, 1937, and the article referred to in footnote [1]).

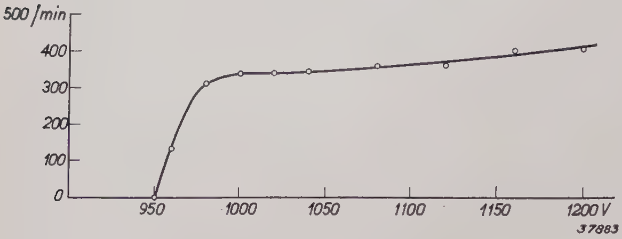

Fig. 4. Count characteristic of the counting tube. A sample of 1 mg of radium enclosed in a lead case 1 cm thick and placed at a distance of 1 m from the counter served as source of radiation. The number of current impulses recorded by the counter is plotted as a function of the voltage on the counting tube. The "counting region" within which the number of current impulses provides a correct measure of the intensity of the radiation extends in this case from about 1 000 to 1 150 volts.

The connections

The connections of the apparatus are given in *fig. 5*. They correspond for the most part to those of fig. 2. As amplifier valve B_1 a valve with a steep slope is used, which gives a high anode current and thus a large fall in voltage on the counting tube with a small increase in the grid voltage. The necessary grid bias cannot in this case, as is usual in ordinary amplifier connections, be obtained with a resistance in the cathode connections, since the valve carries no current in the no-load state. Therefore the bias is taken by means of a potentiometer from the plate voltage apparatus which serves for the supply. For the counting of the current impulses they are further amplified by a second amplifier valve B_2 and applied to a call counter, the rattling of which already makes it possible to estimate the intensity of the radiation by ear without reading it off.

As was stated above, a D.C. voltage of from 900 to 1 200 volts is needed for the counting tube. The generation of such a voltage is of itself no problem; according to the ordinary method, namely the use of a transformer with rectifier valves, fairly heavy constructions are, however, obtained. In order not to load the apparatus with these, a different method has been chosen here. In this periodical [5]) it has already been explained that with the help of a connection of condensers and valves (cascade connection) from an A.C. voltage with the peak value E a D.C. voltage $2E$, $3E$, $4E$, etc. can be obtained. This connection, which is in general only used for obtaining very high voltages (of hundreds of kilovolts), is found to be advantageous in this case also for the relatively low voltage of 1 200 volts. The A.C. voltage is provided by the mains (at 220 volts the peak value is about 300 volts), and can be further regulated with a potentiometer. The four successive stages of condensers and rectifiers with which the high D.C. voltage is obtained are shown in fig. 5. As rectifiers selenium valves are used which in order to obtain the required blocking voltage of 600 volts are in each case built up of about 20 elements piled one on top of the other, each with a blocking voltage of about 30 volts [6]). In this way an extremely small and light unit is obtained as shown in *fig. 6*.

In *fig. 7* a photograph is given of the complete apparatus which can be connected directly to the light mains.

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[5]) Philips techn. Rev. **1**, 6, 1936.

[6]) On the subject of selenium valves and their applications see D. M. Duinker, Philips techn. Rev. **5**, 199, 1940. The selenium elements here used are of a special construction for very small currents.

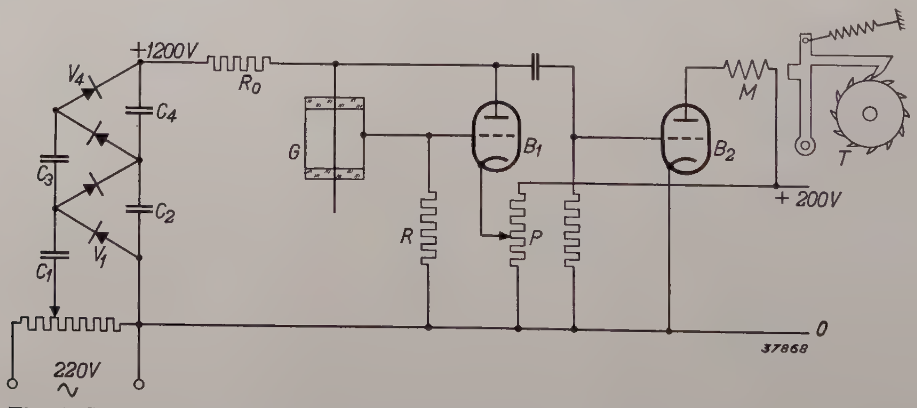

Fig. 5. Connections of the apparatus (somewhat simplified). The connections correspond for the most part to those of fig. 2. The current impulses caused by the counting tube G in the amplifier valve B_1 are amplified in a second valve B_2 and fed to a counting device (call counter) T. This contains a magnetic coil M excited by the anode current of B_2, which at every current impulse attracts a lever which causes a toothwheel to move by means of a hook. The supply voltage for the counting tube is obtained by means of a cascade connection of condensers C_1-C_4 and selenium valves V_1-V_4. The grid bias of the amplifier valve B_1 is regulated with the potentiometer P.

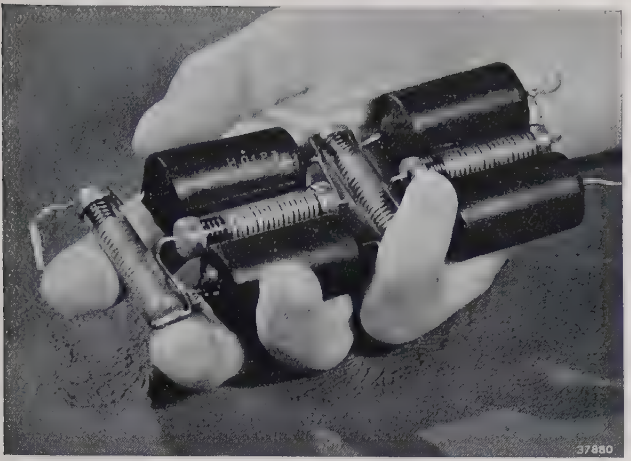

Fig. 6. Cascade connections for 1 200 volts. Each of the valves consists of 20 selenium elements piled one on top of the other in a glass tube and pressed firmly together by a spring.

In conclusion a few words must be said about the possibilities of application. Besides for the applications already mentioned, such as the detection of an electronic radiation for demonstration purposes, the apparatus can also be used in other fields. In hospitals it sometimes happens that radioactive substances which were enclosed in bandages for irradiating a patient are lost. They can often be found by going over the room in which they are thought to be present with an electron counter, which will announce the proximity of the substance by a loud rattle of the counting mechanism. The apparatus may also be useful to the doctor for controlling the possible secretion in the urine of an artificial radiaoctive substance [8]) administered to a patient. The presence of γ-rays, X-rays, ultraviolet rays and visible light can be demonstrated indirectly with the "electron counter", since these radiations free electrons from the cathode of the counting tube (photoelectric effect). In the abovementioned demonstration of radioactivity it will usually be the γ-rays which cause the instrument to register. (This was also the case in taking the photograph of fig. 4). In order to experience no difficulty from daylight while using the tube, it is lacquered black. If a small window is made in the layer of lacquer, interesting effects can be obtained with the instrument. It reacts immediately with an obvious increase in its rattling when a window is opened, since then more ultraviolet radiation, which is very active photoelectrically, enters the room. The lighting of a match is noticed by the instrument at many metres distance, etc. We have already mentioned that cosmic rays cause current impulses in the counting tube. If one does not use a special shield of lead or iron to weaken these rays, the apparatus counts about 13 impulses per minute; with a shield of 10 cm of iron the number falls to 6 per minute.

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[7]) It is known that several years ago in the Netherlands such a case occurred, and a preparation lost in an institution in the Hague was found in a rubbish dump in Drente (a distance of 150 km).

[8]) See on this subject the article of F. A. Heijn and A. Bouwers in the foregoing number of this periodical **6**, 46, 1941).

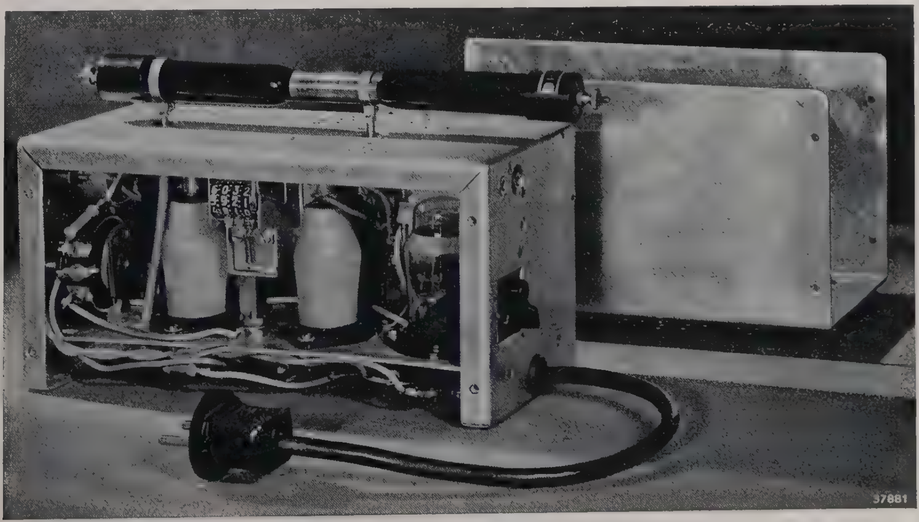

Fig. 7. The complete electron counter opened. On top of the cabinet may be seen the counting tube. Through a small opening in the cover the position of the counting device can be read off. Through two holes on the right side the supply voltage for the counting tube and the grid bias of the first amplifier valve can be varied with a screw driver, if this should be necessary. In the lower part of the right-hand side is the connection for the mains voltage and a switch, above, a connection by which the current impulses can be taken from the valve B_1, and if desired fed to an automatic counting circuit when measurements with a higher resolving power must be carried out. The apparatus is 23 × 12 × 12 cm and weighs only $2^1/_2$ kg.

STEREOPHONIC RECORDING ON PHILIPS-MILLER FILM

by K. de BOER.

534.76 : 681.84.081

Beginning with an ordinary apparatus for recording sound film by the Philips-Miller system, an experimental arrangement has been worked out for the making of stereophonic recording. Two sound tracks must be cut in the film strip in this case. The fact that the tolerances as to time differences in the two tracks are extremely small and the requirement that the stereophonic recording must also be able to be played without the stereophonic effect if desired, led to an arrangement in which two sound recorders side by side cut their tracks on the same roll of film. The mechanical problems which were hereby encountered, as well as several details of the arrangement used for recording and reproduction are briefly discussed.

When the time comes to make use of stereophonic reproduction in the cinema, in broadcasting, etc., and the opinion becomes more and more general that the improvement in quality so obtained is worth the trouble, it will become necessary in the first place to find a process of making stereophonic records on a large scale. One possibility of stereophonic recording has already been discussed some time ago in this periodical, namely, recording on gramophone disc records [1]). Although this method was satisfactory for the purpose then in view: the study of different arrangements for stereophonic reproduction, the determination of the requirements to be made of the sound image, etc., for use on a large scale, particularly in the cinema, it can scarcely be considered. The objections are the same as those which formerly defeated the gramophone record in the development of sound film: the playing time of the gramophone record is too short, and there is no easy method of assembly and synchronization with the corresponding picture film. The first objection is particularly important with stereophonic disc records, since the method of recording limits the playing time to half that normally obtained.

Experiments have therefore been carried out in this laboratory in order to work out a method of making stereophonic records on film strips, and the method and apparatus chosen were those of the Philips-Miller system [2]). A short description will here be given of these experiments which led to the solution of several problems which will also be encountered in the construction of a cinema machine with stereophony.

For stereophonic reproduction the sound in the recording room must be taken up by different microphones, while the sound contribution of each microphone is reproduced by a separate loud speaker in the reproduction room. For each sound contribution therefore a separate "channel" is necessary, and in recording, a separate sound track. In practice it is found that two sound contributions suffice to give a satisfactory stereophonic effect [3]); therefore only two sound tracks need be recorded on the film.

How can these two sound tracks be obtained on the film strip?

The ordinary apparatus for recording and reproduction by the Philips-Miller system, see *fig. 2*, is carried out in duplicate, in order, by alternative use of the two halves, to be able to record and reproduce passages of any desired length without interruption. It was logical to use the two recording systems thus available in our experiments for cutting the two sound tracks, namely by drawing the film from the feed roll in one system along both

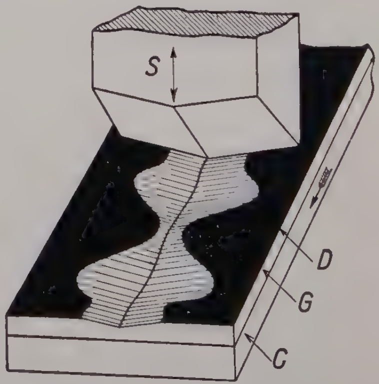

Fig. 1. Principle of sound recording by the Philips-Miller system.

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[1]) K. de Boer, Experiments with stereophonic records, Philips techn. Rev., 5, 182, 1940.

[2]) The principle of this system is shown in *fig. 1*. On a strip of celluloid film *C*, a gelatine layer *G* with a very thin nontransparent covering layer *D* is deposited. This "Philimil" film is pulled along under a wedge shaped cutter *S*, which is moved up and down in the rhythm of the sound vibrations and thereby cuts a transparent track of varying width (the sound track) in the film. The reproduction of this track, like that of photographically recorded sound film, takes place by an optical method. The particulars of the system are discussed in detail in Philips techn. Rev. **1**, 107, 135, 211, 230, 1936; **5**, 74, 1940. On the sound recorder see especially the second article referred to (A. Th. van Urk).

[3]) K. de Boer, Stereophonic sound reproduction, Philips techn. Rev. **5**, 107, 1940; Diss. Delft 1940.

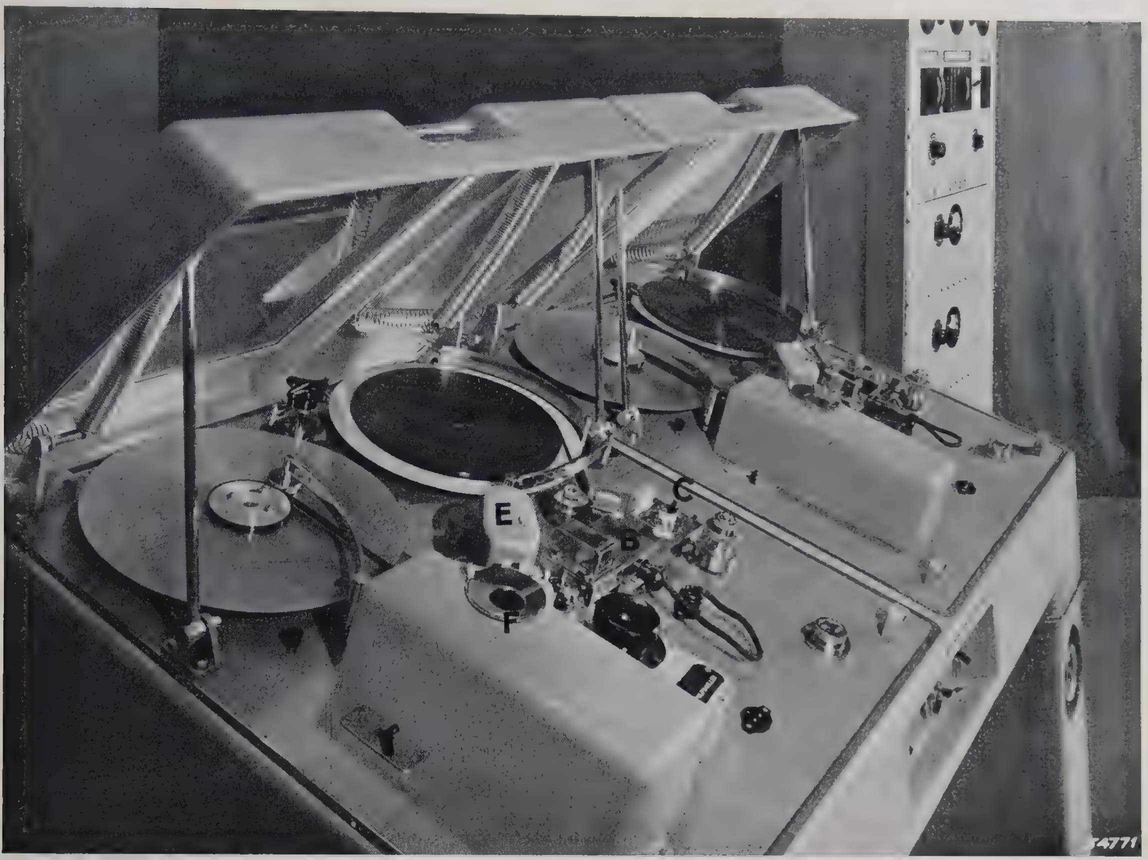

Fig. 2. Apparatus for sound recording by the Philips-Miller system. The machine consists of two similar halves. On the top of each half in the middle may be seen the sound recorder *B*. In *E* and *F* are a lamp and a photocell for reproducing the sound track. To the left and right at the back of each half may be seen the film rolls.

of the sound track cutters to the winding roll in the other system; see the diagram in *fig. 3*. Corresponding points of the two tracks recorded side by side in this way lie at a certain distance *a* (about 1 m) from each other (*fig. 4*). In reproduction the two optical scanning systems, along which the film is moved in the same way as in the recording, must stand at the same relative distance *a* (more precisely, the section of film between the two systems must have the length *a*).

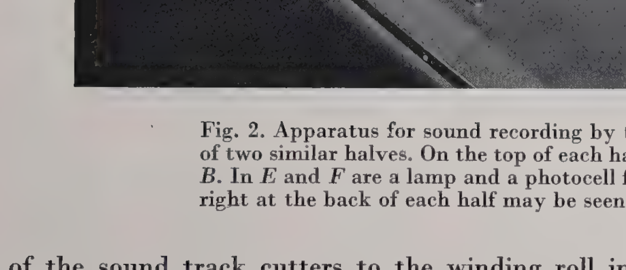

Fig. 3. Diagram showing how stereophonic recordings may be made whereby the two similar halves of the Philips-Miller apparatus are used. A_1 feed roll of film, *F* "Philimil" film, S_1, S_2 cutting rollers on which at G_1 and G_2 the sound tracks are recorded, O_2 winding roll for film. The cutters G_1 and G_2 are at different heights above the cover plates, so that the two sound tracks lie side by side on the film. The film is transported by the roller S_2.

This apparently simple method encountered various difficulties. In the first place, in recording, a certain stretching of the film occurs due to the tension which must be applied to overcome the resistance by the two cutters (see footnote 2)) in cutting the track in the film. With ordinary recordings this stretch causes only a slight, quite inaudible shift in pitch; in stereophonic reproduction, however, it has unpleasant results. Corresponding points on the two tracks are farther apart due to the stretch, and thus do not pass through the two scanning systems at the same time, but with a slight difference. The result is a displacement of the sound image observed by the listener 4)). In order to avoid this effect the requirement should

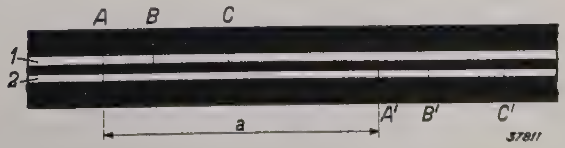

Fig. 4. Diagram of stereophonic sound film recorded according to fig. 3. Corresponding points *AA'*, *BB'*, *CC'* on the two tracks are separated by a distance *a*.

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4) See the article mentioned in footnote 1).

be made that the stretch of the film over a length of about 1 m (the distance a) should not be more than 60 μ! It must also be noted that a constant stretch over the whole film would be harmless, since one could then eliminate the time difference by changing the relative positions of the scanning systems correspondingly. However, the stretch is not constant along the whole film, since the resistance of the strip, and therefore also the necessary tension, depends upon the cutting depth of the cutter, which varies widely for loud and soft passages in the sound. The result of the stretch is therefore irregularly varying time differences between the two sound contributions, and thus a fluctuation of the sound image.

Attempts may be made to avoid stretch by giving the film strip a separate transport mechanism at each of the two sound cutters, so that the section of the film between need not transmit any force; see the diagram of *fig. 5*. The two transport mechanisms must then be coupled with each other in order to make sure that they both transport equal lengths of film in equal times. Such a coupling, however, in general leaves the possibility open for slight periodical variations in the velocity of the film at the position of the cutters. This introduces periodic time differences between the two sound contributions which in turn cause displacements of the sound image. Experiments with such an arrangement showed that it would only be possible to limit this effect sufficiently with fairly elaborate and expensive constructions.

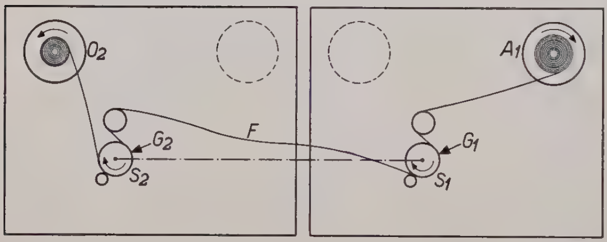

Fig. 5. In order to avoid stretching the film the method of fig. 3 can so be changed that both cutting rollers S_1 and S_2 are driven separately. The two rollers must in this case be rigidly coupled. The letters have the same significance as in fig. 3.

Even if these difficulties were successfully overcome, however, an important objection to the method outlined would remain. As long as the stereophonic sound film has not yet gained a permanent position in the film industry, it is very desirable for stimulating initiative in this direction that the stereophonic film, even without stereophonic effect, should be able to be played off on ordinary sound film machines as well. This is impossible in the method described, since in scanning in the ordinary way the parts of the two sound tracks lying side by side are always made audible at the same time, while they should be reproduced with a time difference of about 3 sec (namely a/v where v = film velocity = 30 cm/sec). The result would thus be that every passage of the recorded speech or music would be made audible twice, at a time interval of 3 sec.

In order to avoid this echo effect the stereophonic film must be recorded so that corresponding points of the two sound tracks lie side by side on the film with a relative displacement of not more than 1 to 2 mm. The problems of stretch and of periodic time differences are thus also eliminated [5].

These considerations lead to an arrangement in which two sound recorders side by side cut their tracks on the same cutting roller. This idea could not immediately be realized with the existing construction of the Philips-Miller recorder, as is obvious from a consideration of *fig. 6*. It may be seen how on the one hand film and cutting roller, and on the other cutter, armature and magnetic circuit of the recorder are arranged, in relation to each other. If one imagines a second sound recorder, as it were a mirror image of the first, introduced on the other side of the roller, so that the two recorders are side by side, one comes into conflict with the law that two different things cannot be situated at the same time at the same point in space. The most difficult problem arose due to the axis of the cutting roller. As may be seen in fig. 6*a* it would run straight through a pole piece of the second sound recorder. To avoid this, either the distance between axis and cutter, thus the diameter of the cutting roller had to be increased, or the width of the pole pieces of the second sound recorder decreased. The latter is not immediately possible, since the magnetic resistance of the pole pieces may not be made too large. The first solution also has harmful results: the peripheral velocity of the cutting roller, *i.e.* the film speed, is fixed; a larger roller must therefore turn more slowly. Because of this the energy content of the flywheel mounted on the axle of the roller, which serves to eliminate the influence of variations in the cutting force, is decreased, while the couple which tends to cause irregularities is made larger due to the larger diameter of the cutting roller (longer lever). Fortunately it was found that in the existing construction the pole pieces of the recorder as well as the flywheel of the drive were of sufficiently generous proportions to make it possible to find a satisfactory compromise. The width of the pole pieces needed only to be reduced by a few mm, while the diameter of the cutting roller could be increased from 35 mm to 70 mm.

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[5] It might be thought that the "echo" could also be avoided by only reproducing one of the tracks and covering up the second track in the machine for playing. This would, however, give an unbalanced reproduction of the recorded music, since in stereophonic reproduction the two microphones are expressly so placed that each microphone "hears" the sources of sound in a certain part of the room less well than the other. In order to obtain a satisfactory whole the two sound contributions must in any case, either with or without stereophonic effect, be recombined. Where in this article the term "ordinary" sound film machine is used, it must be kept in mind that "Philimil" film can only be reproduced directly in the corresponding machine, while for the reproduction in an ordinary cinema machine the sound track must first be transferred to the picture film.

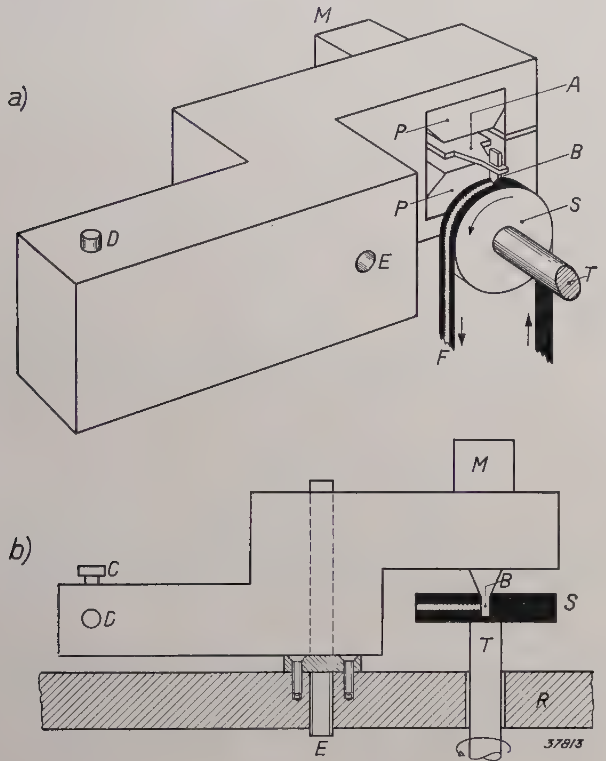

Fig. 6. The sound recorder of the Philips-Miller system. In *a* the relative position of armature *A*, cutter *B*, film *F* and cutting roller *S* may be seen, while *b* shows the assembly on cover plate *R* of the machine. *P* pole pieces, *M* permanent magnet, *T* axis of the cutting roller (also called sound or tone axis), *E* axis about which the whole recorder can be rotated, *D* pin for regulating the cutting depth. The screw for regulating *D* is moved by the knob *C*.

Other less essentiel structural changes were necessary for the body of the recorder and for the magnet which excites the magnetic circuit of the recorder. In the original construction the cutting roller is set into the body of the recorder (see fig. 6), which is a convenient method of giving firm bearings to the shaft *E*, and thereby of fixing as well as possible the relative positions of cutter and cutting roller. Now, in order to be able to place the two recorders side by side, they were made flat, see *fig. 7*. As to the magnet, in the original construction it was set above the pole piece as may be seen in fig. 6.

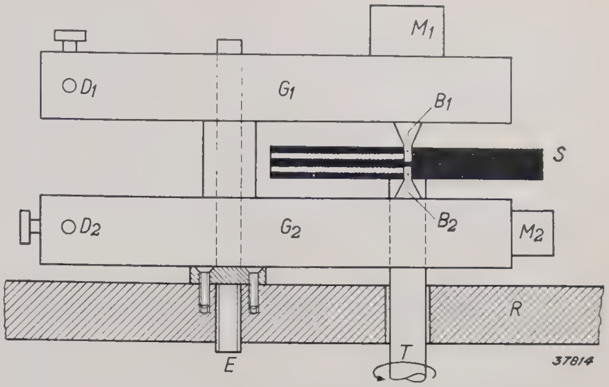

Fig. 7. Construction and arrangement of the two sound recorders G_1, G_2 for cutting two tracks on the same cutting roller *S*. The recorders are on the common axis *E*. Letters have the same significance as in fig. 6.

In the second recorder, which must be as a mirror image to the first, the magnet would fall below the pole piece, *i.e.* between the latter and the cover of the machine. The result would be that the distance between the cutting roller and the cover, which is already greater due to the insertion of the second recorder, would have to be further increased by the height of the magnet. The point of application of the cutting force which acts obliquely on the axle of the cutting roller would thereby lie too far away from the bearings of this axle. A solution was found here by setting the magnet on the pole piece at the side, whereby the course of the lines of force remains practically the same in pole pieces and armature. It is true that the magnet is hereby placed in a position where the space is very much limited by the guiding rollers for the film and by other parts; by using the newest type of magnet steel, however, the dimensions of the magnet, compared with those of the former construction, could be reduced so that no difficulty was experienced.

The final construction used in our experiments is shown in the photographs of *fig. 8* and *9*.

In order if desired to be able to play off the stereophonic film on an ordinary machine, another condition must be satisfied: the total width of the two sound tracks must not be greater than 2 mm. To achieve this purpose each recorder in the arrangement described was provided with a cutter which has the form of half a wedge, see *fig. 10*. The double track obtained in this way, an example of which is reproduced in *fig. 11*, corresponds entirely to a track recorded in the normal way except for a narrow black stripe along the centre and the essential time and intensity differences of the two halves [6].

Certain precautions had to be taken for the precise adjustment of the cutters. Both cutters must have the same cutting depth in order to obtain the same depth of modulation in the two halves

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[6] In playing on an ordinary machine the two sound contributions are as it were "mixed" in the optical scanning system, which practically comes down to the same thing as the usual mixing of the contributions of different microphones by an electrical method.

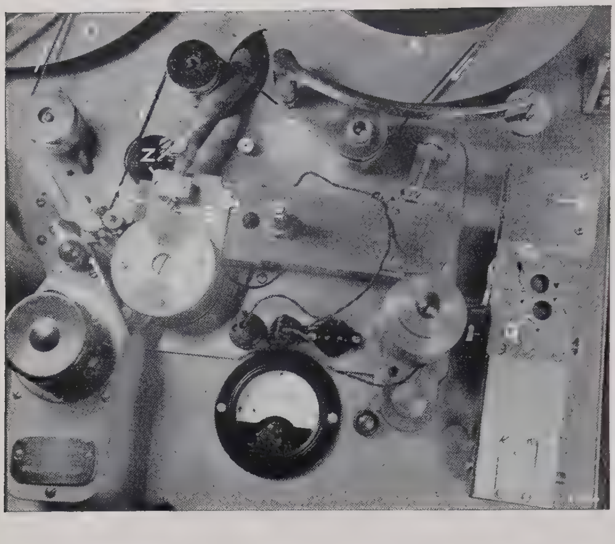

Fig. 8. The lower sound recorder G_2 ready for use. The upper sound recorder G_1 lies at the side. B_1, B_2 are the cutters, S the cutting roller; F the "Philimil" film whose path from the roll A to the roll O is indicated by arrows; E the axis which bears the two recorders; Z mouthpiece and tube of a suction arrangement for removing the shaving cut from the film; M_2 magnet, Q rotating ring with excentric bore for the axis E.

of the double track. The cutting depth is regulated separately for each recorder by screwing out the pin D visible in figs. 6 and 9 more or less with a micrometer screw C. At the beginning or end of the recording both cutters are set on the film or taken off it simultaneously by means of a cam which pushes the two pins D away at the same moment and thereby turns the recorders about the common axis E; see fig. 9.

A second adjustment relates to the relative distance between the cutters in the direction of length of the film. We have stated above that this distance may amount to a maximum of 1 or 2 mm for the playing of the resulting film on an ordinary machine (without stereophonic effect). For playing with stereophonic effect, where the two sound tracks are reproduced separately, the restriction in this respect is very much greater. A time difference between the two sound contributions of only 2×10^{-4} sec is already observed as a displacement of the sound image [4]). This time difference corresponds to a difference in position on the film of $v \times 2 \times 10^{-4} = 0.06$ mm. (From this the above-mentioned tolerance for the stretch is also derived).

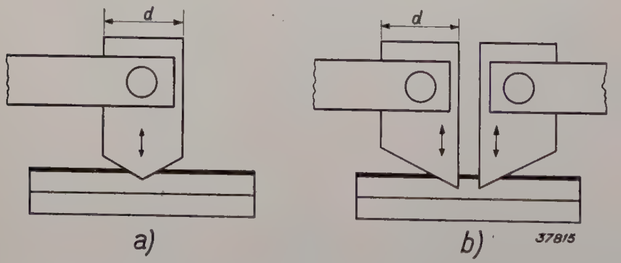

Fig. 10. For cutting the two sound tracks two sapphire cutters are used (b), which are half wedge-shaped, in contrast to the complete wedge-shape of the ordinary cutter (a). The width d of each cutter remains the same in order to be able to clamp the cutter sufficiently firmly to the armature of the sound cutter. The angle of the wedge is actually much more obtuse that here shown (87°).

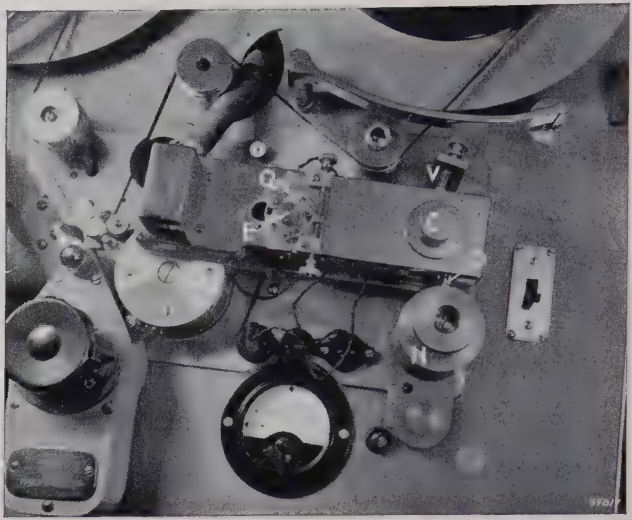

Fig. 9. Like fig. 8 with the upper sound recorder in position. With the cam N (excentric drum) both the recorders are turned about the axis E at the same time against the springs V so that the cutters begin to work.

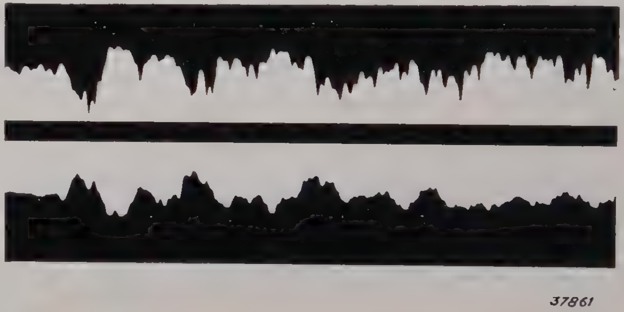

Fig. 11. Section of a stereophonic sound film recorded by the method described. The two sound tracks in which the two sound contributions are recorded are separated by a narrow black stripe. The differences may be seen in intensity and time of the two vibration forms whereby the stereophonic effect is obtained. The intensity differences are greatest for the high frequencies: the latter are much stronger in the upper track than in the lower.

In order to be able to adjust the position of the cutters with such precision the shaft E in one recorder is excentrically borne by a rotating ring Q, see fig. 8. By a slight rotation of the ring with the help of the screws visible in fig. 9, the recorder with cutter and all is displaced slightly in the direction of length of the film; the adjustment can be carried out by this means with a precision of less than 0.02 mm [7]).

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[7]) This method corresponds to that which was formerly used in this laboratory for placing the holes in the Nipkow disc. See H. Rinia and L. Leblans, Philips techn. Rev. 4, 42, 1939, especially page 47.

For stereophonic reproduction the film may be illuminated in the ordinary way through a narrow slit, while the light transmitted by each half of the double track must be received in a separate photocell. This splitting of the transmitted beam, which may be accomplished very easily with the help of a mirror placed in front of one half of the slit, would here, due to the narrowness of the beam (2 mm), lead to a very fine and delicate construction. The following method has therefore been chosen. With the help of an objective a sevenfold enlarged image of the film is projected on a slit. Half of this image is deflected by a mirror. The arrangement may be seen in *figs. 12* and *13.*

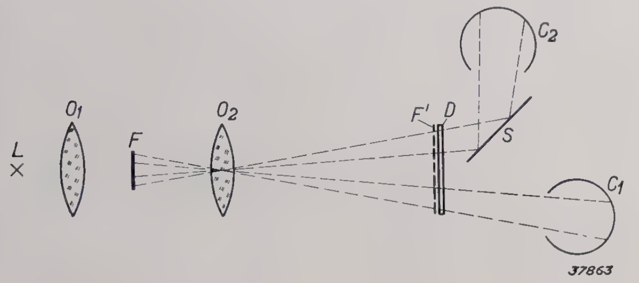


Fig. 12. Arrangement for the reproduction of stereophonic film. With the light source L and the lens O_1 the film F (which is drawn toward the observer perpendicularly to the plane of the drawing) is illuminated, while the lens O_2 projects a sevenfold enlarged image F' of the film on the slit D. Half of the beam transmitted through this slit, corresponding to one of the two sound tracks, is directed to the photocell C_2 with the help of the mirror S, while the other half of the beam is received by the photocell C_1. The alternating currents given by the two photocells are amplified separately and fed to two loud speakers.

In conclusion we wish to point out that the ordinary "Philimil" film is wide enough (7 mm) to contain, beside the normal or double track of 2 mm, still another sound track. This possibility may be of importance when, as is at present often the case in the cinema, it is desired to record and reproduce the low and high tones separately. As has already been mentioned [3]) the low tones (below 300 c/s) contribute little or nothing to the stereophonic effect. The corresponding sound track therefore need only be a single one, and the position of points on this track with respect to corresponding points on the other (double) track need to be carefully determined. The simple method outlined in the beginning, of recording at differents spots, might therefore be used here, since it would in any case be difficult to record three tracks at the same spot side by side. This extension of the method can, however, only come under consideration when the requirement that stereophonic films must be able to be played on "ordinary" machines will have been outgrown.

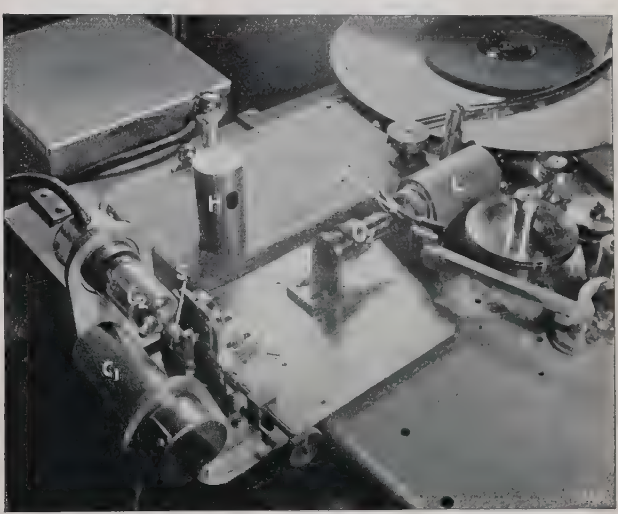


Fig. 13. Photograph of the arrangement for playing stereophonic film. Letters have the same significance as in fig. 12. The cover H of the photocell C_2 has been removed.

SWITCHBOARD WIRE FOR TELEPHONE INSTALLATIONS

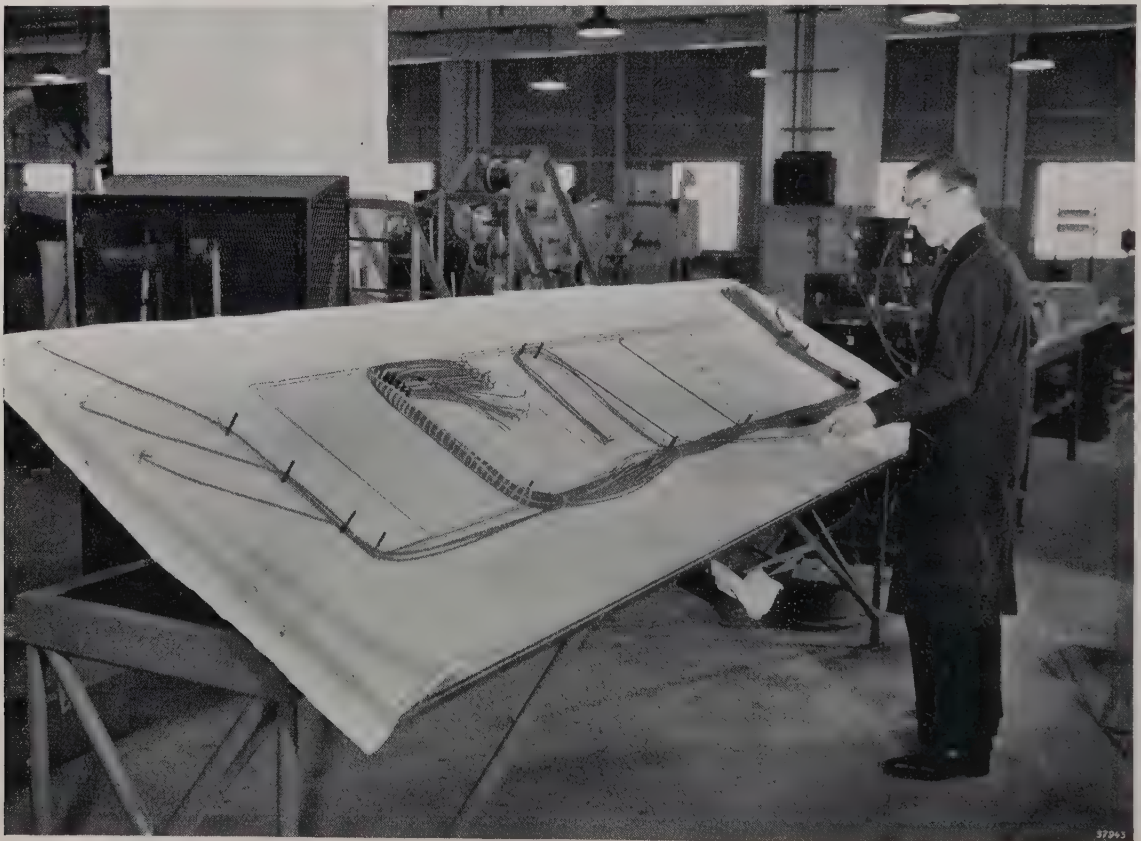
by H. FEINER and J. HOEKSTRA. 621.315.616

Switchboard wire for telephone installations is usually insulated with textiles which are provided with an impregnation or a layer of lacquer for protection. In this article the improvement in the insulation is discussed which could be attained by a special choice of raw materials. Especial attention is paid to chlor-rubber lacquer which combines excellent dielectric properties with the advantage of being non-combustible. In conclusion, the technical use of switchboard wire is discussed.

The technical installations in modern telephone exchanges and repeater stations are built up of bays which contain numerous connections and are connected to each other and to the cores of the telephone cable (cable distributor bay).

Requirements are made of these connections, which almost always consist of pairs, which in general correspond to the requirements made of telephone cables. In the first place there is the requirement of adequate insulation. Furthermore, both in the case of switchboard wire and in that of a telephone cable, a compromise must be sought between the total cross section of the insulated double wire and the capacity per unit length. The thinner the layer of insulation, the smaller the cross section and the higher the capacity. With telephone cables many kilometres in length the capacity between the wires with A.C. voltage amounts in a certain sense to a shunt for the apparatus connected, which, even for the relatively low frequencies of speech, may lead to considerable voltage losses. In order to keep these losses as low as possible an upper limit of about 30 pF/m is prescribed for this capacity. In the case of the telephone switchboard wires which have a maximum length per connection of 20 to 30 metres, a capacity of 100 tot 130 pF/m can be allowed. The fact that a decrease in the cross sections can hereby be obtained is a great advantage in connection with economical assembly in the bays, where within a relatively small space a very large number of connections must be carried out.

This accumulation of connecting wires forms an extremely complicated whole during the assembly (*fig. 1*), and one is therefore compelled to mark the wires. The usual method of doing this is to give the wires different striking colours or colour combinations. It is therefore not by chance that a bunch of telephone wires always presents such a pleasant appearance, aesthetics is here the daughter of technology.



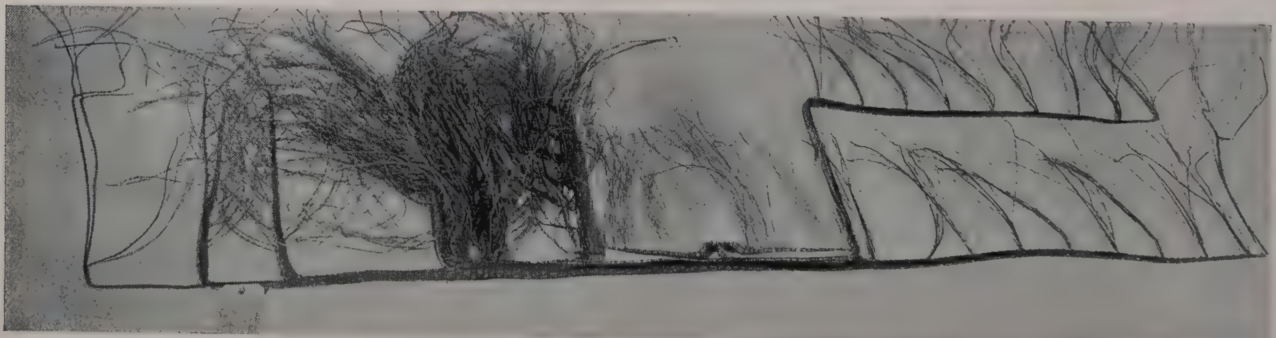


Fig. 1. Above: the wires of a telephone bay are laid out on an assembly table and bundled. Below: the result obtained. In the photograph, which does not show the colours, the sorting out of the wires would appear to be hopeless.

The requirement must therefore be made of the layer of insulation that it can be prepared in different colours. In order that the colours shall not become dimmed after some time by dust and dirt it is also very desirable that the surface should be smooth.

Finally it has become more and more desirable lately that telephone switchboard wire should not be inflammable, at least that it should not burn further when it has once been ignited. This requirement should be strictly enforced for the sake of uninterrupted telephone service, since it has already been demonstrated more than once what an enormous disturbance can be caused in telephone communication by a fire, which is in itself not serious, but which attacks the bunches of switchboard wire.

Summarizing we may therefore formulate the following requirements for the insulation of a telephone switchboard wire:

1) high specific resistance,
2) low dielectric constant,
3) smooth surface with bright colours,
4) non-inflammability.

When the wire is used in installations for carrier-wave telephony, in which alternating currents of much higher frequency occur than in normal low-frequency telephony, the value of the capacity is of much more importance, while moreover attention must also be paid to the dielectric losses of the insulation material. The ordinary insulation materials used for telephone switchboard wire cannot therefore be used for wiring carrier-wave systems. In this article we shall first discuss the construction of the insulation of a mechanically strong, non-inflammable switchboard wire for low-frequency telephony, and then show how it has been possible to improve the dielectric properties of the layer of insulation to such an extent that a wire is obtained which is also suitable for carrier-wave systems.

Telephone switchboard wire for low-frequency telephony

The customary insulation of telephone switchboard wire consists of textiles which are impregnated in order to obtain a more compact whole. Cotton is spun or braided around the wire and impregnated with wax, paraffin, ceresin or a mixture of these substances. The insulations thus obtained are satisfactory from an electrical point of view in a dry atmosphere; the surface, however, is not sufficiently smooth, and these wires are very inflammable.

The inflammability disappears when insulation waxes containing chlorine are used as impregnating agent (chlorinated naphtaline for example). Upon heating, these substances develop gases which have a smothering effect and prevent the insulation of the wire from bursting into flame. The waxes containing chlorine have, however, the practical disadvantage that when the impregnating agent must be heated during manufacture very poisonous gases are developed, while the solid insulation waxes may sometimes also have toxic effects through the skin. This objection has been successfully met by using chlor-rubber instead of chlorine waxes. Chlor-rubber is one of the so-called high polymers, which are organic compounds with very long chain molecules and which are too viscous to be used as impregnating agents by themselves. Softeners are, however, known for such substances, usually liquids with low vapour pressures which can be mixed with the high polymers (or resins) in question and give them greater elasticity. With a non-inflammable softener chor-rubber gives a very fire-resistant impregnating agent, which in combination with normal textile can be successfully used in all cases where the electrical requirements are not too high. *Fig. 2* shows a piece of telephone switchboard wire prepared in this way.

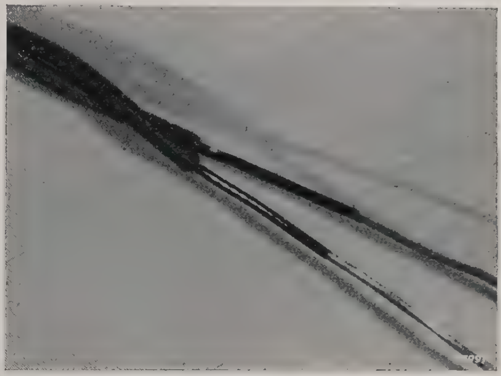


Fig. 2. Cross connection wire consisting of a tinned copper core surrounded by a layer of enamel lacquer and a layer of impregnated cotton.

If a smoother surface is desired than is obtained in this way, the surface of the textile can be covered with a layer of lacquer. Such a layer of lacquer is found to protect the textile insulation just as well as impregnation, so that impregnation is unnecessary. At the same time the dielectric constant is lowered. The usual lacquers for this purpose, which do not, however, satisfy the requirement of non-inflammability, have cellulose derivatives as bases, usually cellulose acetate, a substance which is also used for making artificial silk (acetate silk). The lacquered wire is becoming more and more popular since it is better than the impregnated wire in all the properties mentioned until now.

The influence of moisture

One general disadvantage of the insulation agents described is that the protection against the influence of moisture is only temporary. This is true for both the impregnated and the laquered wire. It is found that the absorption of moisture by the textile is slowed up by covering it with a layer of lacquer, but that it is quantitatively scarcely diminished at all. Protection against the influence of moisture is thus only obtained when this influence is of short duration. Even when materials having a hydrocarbon character are used for impregnation or lacquering, which materials are particularly impenetrable for water, after several days, the textile fibre nevertheless reaches an equilibrium with the moisture content of the surrounding atmosphere. Because of this, for example, with dry cotton in an atmosphere with a relative humidity of 90 per cent, which is quite common near the sea, the dielectric constant may increase by a factor 1.5, the dielectric phase displacement by a factor 5 and the conductivity by a factor 10^6.

It is chiefly the great increase in the dielectric losses in moist air which makes the types of wire discussed unsuitable for carrier systems. In the case of low-frequency telephony on the other hand, only the increase in conductivity is disturbing. This is manifested with a D.C. voltage by corrosion phenomena in the first place. The copper core is electrolytically attacked by the moisture so that ions enter the moisture and thus spoil the insulating property. This process has been completely suppressed by providing the switchboard wires with a layer of enamel laquer under the textile. As has been explained in a previous article in this periodical¹) such a layer is practically insensitive to moisture as far as its insulation capacity is concerned. The increase in the conductivity due to the action of atmospheric moisture is thus practically eliminated. The influence of the moisture on the dielectric properties of course remains.

In the development of a switchboard wire for carrier systems the combatting of the influence of moisture forms the chief problem ²). In addition there is also the problem of making the lacquered wire non-inflammable as has been done for the impregnated wire.

Switchboard wire for carrier systems

In the development of the switchboard wire for carrier systems the composition of the insulation just described is retained in principle: a tinned ³) copper wire is covered with a layer of enamel around which is textile and then a layer of lacquer. By suitable choice of textile and lacquer the sensitivity to moisture of the wire is reduced as much as possible and the wire made non-inflammable.

As for textile, cotton (cellulose) and viscose (cellulose hydrate) are much too hygroscopic; real silk and various kinds of acetate silk ⁴) may, however, be used. Real silk was rapidly superseded since it is several times as expensive as a good acetate silk (diacetate silk) which is just as good as real silk from an electrical point of view (mechanically real silk is better). Triacetate silk is even better than real silk electrically, and its price is about the same.

In order to give some idea of the electrical properties of kinds of textiles the variation of the insulation resistance, the dielectric constant and the dielectric phase displacement as functions of the relative humidity of the air are given for a number of textiles in *figs. 3, 4* and *5* ⁵). The difference between cotton and artificial silk is particularly large at

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¹) J. Hoekstra, Properties and applications of enamelled wire; Philips techn. Rev. **3**, 39, 1938.

²) This problem is particularly important where carrier telephony must be applied in tropical or subtropical countries, where the air is often very moist. Carrier telephony may offer an economically advantageous possibility of fulfilling a function which is often necessary in such countries: that of connecting two communities between which a large number of conversations must be conducted simultaneously, and whose distance apart is so great that the extra expense of a cable with many cores would be greater than the extra expense of a carrier-wave apparatus.

³) The copper wire is tinned in order to facilitate soldering. As to the mechanical properties of the enamel layer, an untinned wire would be better, since the enamel adheres less well to tin than to copper. Nevertheless, the tinned and then enamelled wire can be wound around a mandril equal to twice the diameter of the wire without the occurrence of cracks in the enamel layer.

⁴) Cellulose acetate or acetyl cellulose is a compound of cellulose with one or more molecules of acetic acid per glucose residue with the splitting off of a molecule of H_2O. The cellulose molecule consists of a large number of glucose molecules coupled together; each glucose molecule contains three hydroxyl groups (OH-groups) which give the cellulose a very hygroscopic character. The greater the number of these groups which are esterified, the less hygroscopic the product. The decrease in hygroscopocity means at the same time a decrease in the influence of atmospheric moisture on the dielectric properties. Therefore triacetyl cellulose is better than diacetyl cellolose. The former, which no longer contains any unsaturated OH-groups, is, however, difficult to work: due to the lack of hydrophilic hydroxyl groups cellulose triacetate is insoluble in technically useful solvents, and therefore unsuitable for spinning. At the present time methods are known of doing so in spite of this fact; the triacetate silk so obtained is, however, considerably more expensive than diacetate silk.

⁵) The measurements were carried out on wires which had two layers of textile spun around them. The results are of only relative value since they depend on the spinning technique used.

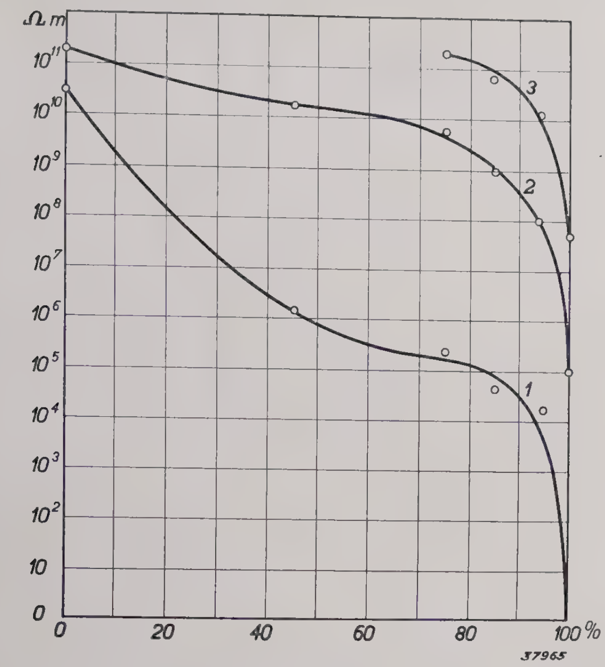

Fig. 3. Insulation resistance of different kinds of textiles as a function of the relative humidity of the air to which the wires were exposed for 48 hours at 25 °C. *1* cotton, *2* diacetate silk, *3* triacetate silk. It is found that the insulation values in the dry state are not very different, but that at high relative humidities cotton is the poorest and triacetate silk the best.

higher degrees of humidity. Triacetate silk is appreciably better than diacetate silk, but the difference in quality is not enough to make up for the much higher price of triacetate silk in all cases. Therefore diacetate silk will generally be used, and triacetate silk only when very strict requirements are made about the insensitivity to moisture.

As stated above acetyl cellulose can also be used for the lacquer layer. However, while the artificial silk made of acetyl cellulose which lies around the wire as a porous mass exhibits satisfactory dielectric properties, the same material in a compact form as a layer of lacquer is much less satisfactory. In the latter case the dielectric constant is much higher and the dielectric losses, which are characteristic of the material, are much more disturbing. Triacetyl cellulose cannot be used instead of diacetyl cellulose because the former is insoluble in technically useful solvents, and therefore unsuitable for a lacquer. Other cellulose derivatives, however, can be used, such as ethyl cellulose and other cellulose esters, as well as nitro-cellulose[6] and certain cellulose tri-esters. Some of these substances actually offer greater resistance to moisture than does acetyl cellulose. The improvement obtained is not, however, decisive.

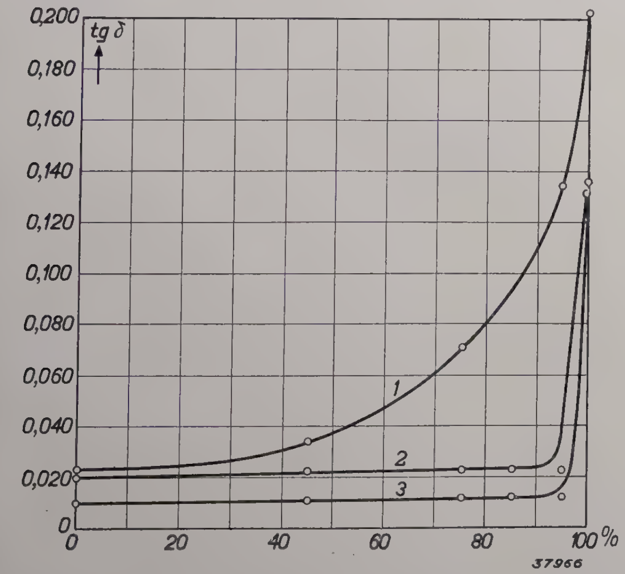

Fig. 4. Dielectric phase displacement at 1.5 × 10^6 c/s (wavelength 200 m) for different kinds of textiles as a function of the relative humidity of the air. *1* cotton, *2* diacetate silk, *3* triacetate silk.

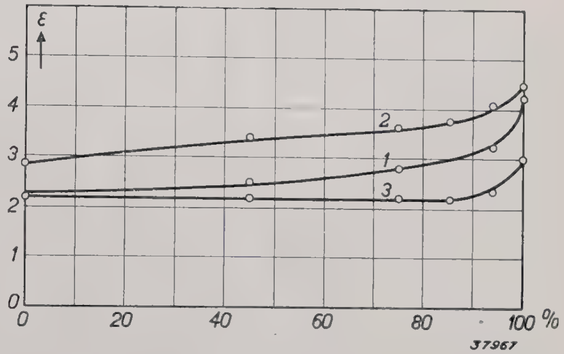

Fig. 5. Dielectric constant of cotton (*1*), diacetate silk (*2*) and triacetate silk (*3*) as a function of the relative humidity.

Besides the cellulose products there is still a large number of other laquer substances. These substances, several of which are mentioned in the article referred to above on enamel-laquer wires, are also artificial or natural high polymers, to which resins are sometimes added to increase the hardness, and more often softeners to increase the elasticity. With a suitable choice from among these substances lacquers can be obtained which are more resistant to moisture than the cellulose derivatives and which also possess good mechanical and electrical properties.

We have attempted to combine the possibilities of the high polymers and resins with the requirement of non-inflammability, and have carried out experiments with chlor-rubber which has already been mentioned as an impregnating agent. It was found that from chlor-rubber in combination with a suitable softener a lacquer can be prepared which is far superior to the other lacquer substances mentioned in the foregoing, not only in respect to its non-inflammability, but also in respect to its dielectric properties. It has the highest insulation

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[6]) This is, however, not very stable and very inflammable.

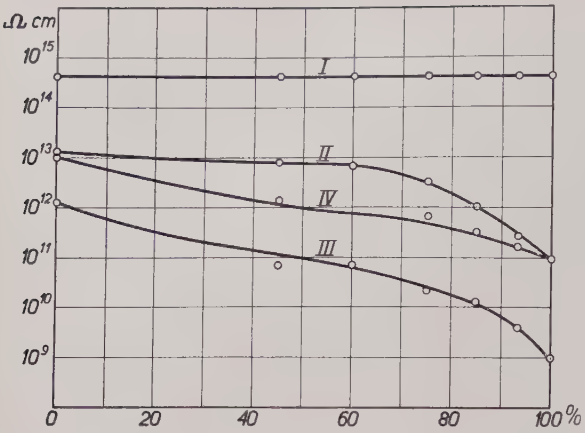

Fig. 6. Insulation resistance of different kinds of lacquer as a function of the relative humidity.

I chlor-rubber lacquer
II ethyl cellulose lacquer
III acetyl cellulose lacquer
IV nitrocellulose lacquer.

It may be seen that chlor-rubber has by far the highest insulation resistance; acetyl cellulose has the smallest insulation resistance, and at the same time it decreases most rapidly with the relative humidity.

resistance, the lowest dielectric constant and the lowest dielectric losses. Moreover, the change in its properties upon a variation in the moisture content between 0 and 100 per cent is almost inappreciable. In *figs. 6*, *7* and *8* the dielectric properties of a number of lacquer substances are given; the superiority of chlor-rubber is very obvious.

As to mechanical properties, chlor-rubber is somewhat less favourable than the other lacquers customarily used in insulation technique. It has been found that this can be remedied by covering the chlor-rubber layer with some kind of cellulose lacquer. Since the electrical field strengths are weakest on the outside, the dielectric properties of the whole combination are made only slightly poorer. In this way a product is obtained which satisfies high requirements electrically as well as mechanically, and which is insensitive to moisture and non-inflammable.

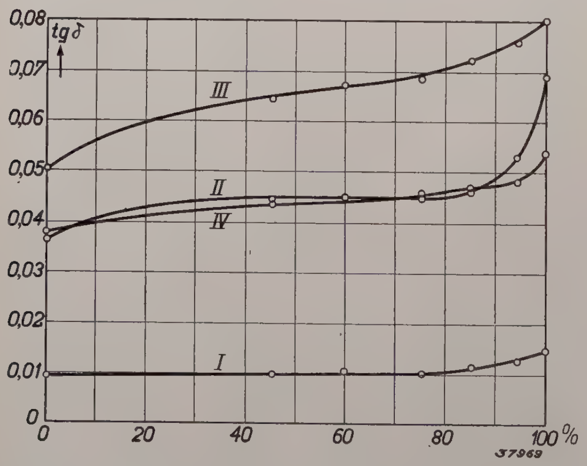

Fig. 7. Dielectric phase displacement at 1.5 × 10⁶ c/s (200 m) for different kinds of lacquer as a function of the relative humidity. The Roman numerals have the same significance as in fig. 6. Chlor-rubber again exhibits the most favourable behaviour.

The manufacture of switchboard wire for carrier systems

The switchboard wire described consists of a tinned copper core, surrounded by four layers of insulation: a layer of enamel, a layer of acetate silk, a layer of chlor-rubber lacquer and a layer of cellulose lacquer. The manufacture of this wire is briefly as follows.

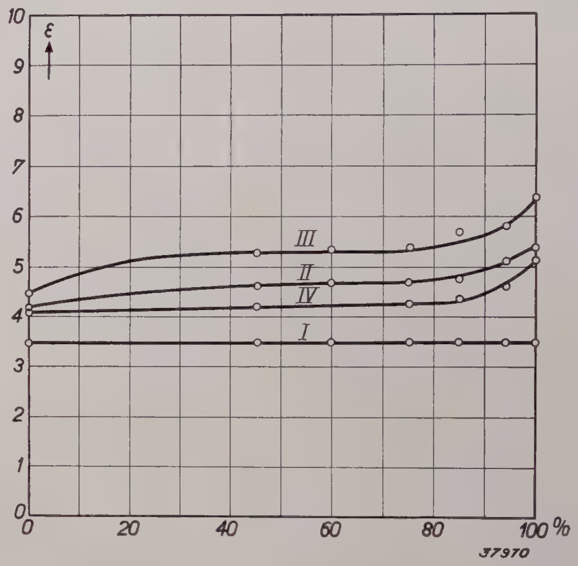

Fig. 8. Dielectric constant at 1.5 × 10⁶ c/s for different kinds of lacquer. The numerals have the same significances as in figs. 6 and 7. Chlor-rubber is again the most favourable.

Tinned copper cores, usually of 0.6 or 0.8 mm diameter are heavily enamelled. The tinning of these cores demands particular care since the tin layer is heated above its melting point when the wire is enamelled, and therefore every point where there is an excess of tin leads to disturbing irregularities in the enamel layer. The thickness of the enamel layer is about 0.06 mm, *i.e.* about 1.5 times the usual thickness. The number of spots where defects in the insulation occur is considerably reduced by this increase in the thickness. If, for example, the number of spots is investigated at which the wire gives a breakdown at 120 volts when it is drawn through a vessel of mercury, a reduction from 1 per 5 m to 1 per 60 m is found.

The artificial silk is now wound around this enamelled core, in four layers for instance. The silk is laid on in loosely twisted strands and in the successive layers it is wound alternately to the left and to the right. The outer layer may to advantage consist of real silk since that is mechanically stronger. This outer layer of textile is made in one or more colours. Over this come the layers of lacquer. These layers, chlor-rubber and over that cellulose lacquer are deposited separately in several extremely thin layers in order to save time in drying, since the sum of the drying times of for instance 10 thin layers is considerably less than that of one layer 10 times as thick. Moreover, such a thick layer of lacquer would not possess the smooth surface which is desired for these wires.

Until now we have spoken only of the manufacture of a single wire. If we now pass on to the manufacture of pairs and the combination of a number of pairs to a cable such as is used in the connections between two bays, quite different problems of construction are encountered. These arise mainly from the requirement that an A.C. voltage acting on a pair may not be transmitted to another pair by capacitative or inductive action. Such couplings give rise to cross talk, *i.e.* the phenomenon in which when an A.C. voltage is applied to one pair at the beginning of the cable a part of that voltage is detected on other pairs as well at the end of the cable. In order to combat these couplings the different pairs are twisted together at a certain pitch before they are twisted in concentric layers into a compact cable. The direction of twisting for the successive layers of the cable, like the pitch of the pairs, is chosen as favourable as possible in connection with the combatting of capacitative and inductive influences, and the pitch of adjacent pairs is different.

When very heavy requirements must be made as

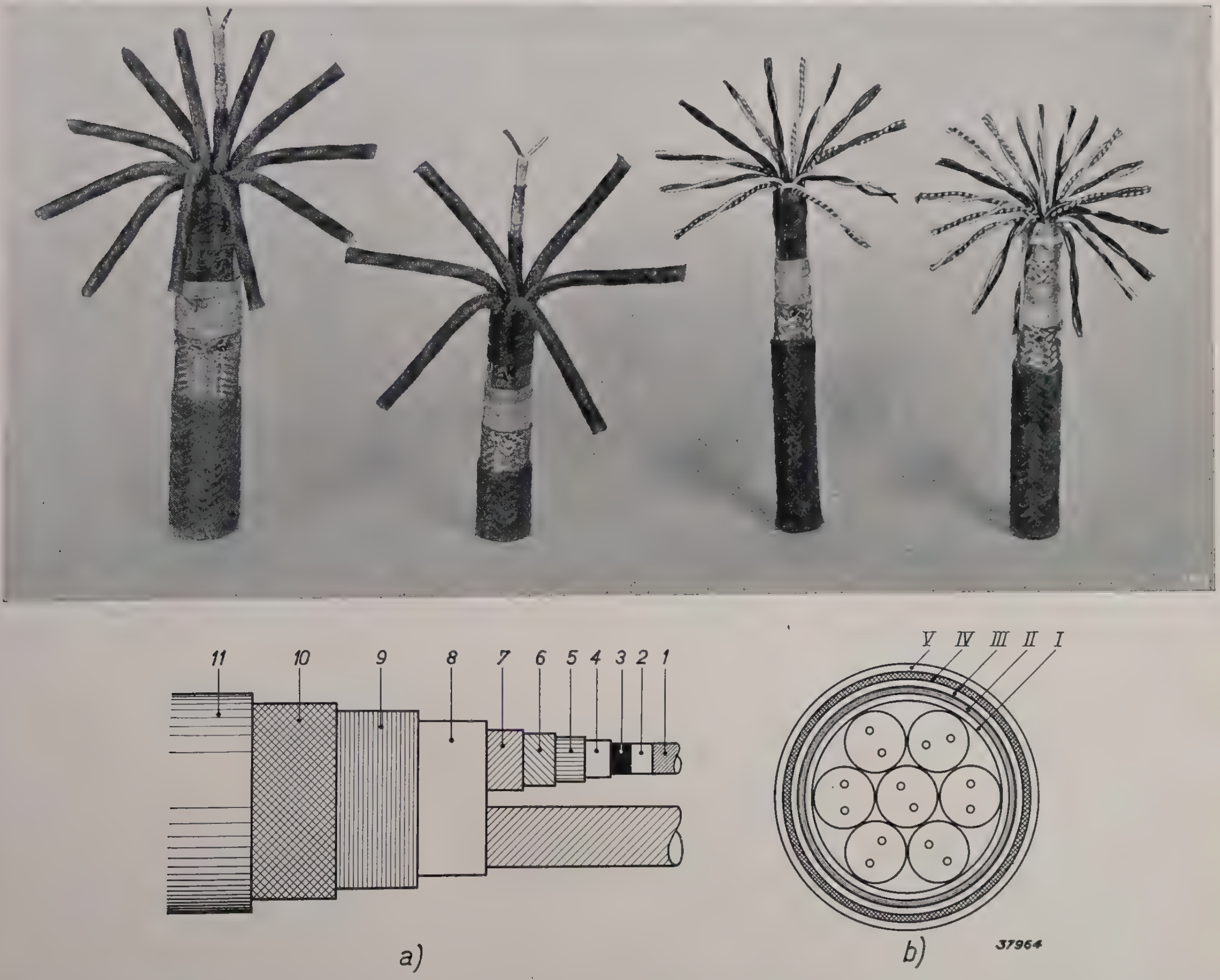

Fig. 9. Cables with shielded and non-shielded pairs. Below, a diagrammatic cross section; *a* of a shielded pair, *b* of a cable with seven shielded pairs.

1 copper core,
2 tinned surface,
3 enamel layer,
4 diacetate silk,
5 coloured real silk,
6 chlor-rubber lacquer,
7 cellulose lacquer,
8 braided layer of artificial silk,
9 film layer,
10 braided covering of tinned copper wire,
11 braided layer of cotton impregnated to be non-inflammable,
I braided cotton,
II film layer,
III layer of spun cotton,
IV braided tinned copper wire,
V braided cotton impregnated to be non-inflammable.

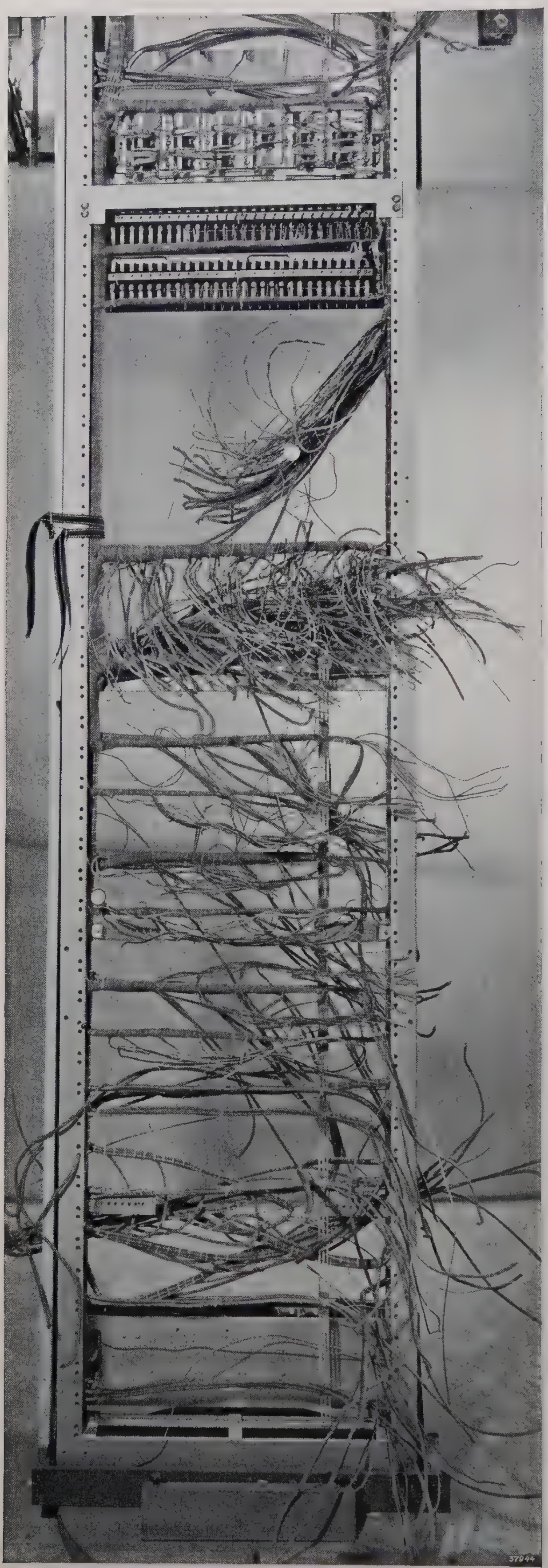

Fig. 10. The bundles of wires of a telephone installation are mounted in the bay.

to the absence of mutual couplings, shielded cables can be used. In the construction of these cables as here described each pair is surrounded by braided tinned copper wire. In *fig. 9* the construction of a shielded and a non-shielded pair may be seen; the text below the figure gives the details. Finally in *table I* a survey is given of the most important technical properties of these cables.

Table I

Properties of shielded and non-shielded cables manufactured by Philips, after tropics test 4)).

Property	non-shielded pairs (0.6 mm Ø)	shielded pairs (0.8 mm Ø)
Working capacity*) in pF/m	max. 100	max. 130
Loss factor*) tan δ at 1 800 c/s.	$\mathrm{tg}\delta < 0.1$	$\mathrm{tg}\delta < 0.1$
Loss factor*) tan δ at 1 800 c/s before tropics test	$\mathrm{tg}\delta < 0.05$	$\mathrm{tg}\delta < 0.05$
Insulation resistance in MΩ at 500 V D.C. voltage for a cable of 10 m**)	$>10^4$	$>10^4$
Test voltage**)	2 000 V, 50 c/s, 2 Min.	
Cross talk damping for a cable of 10 m length***)	>90 dB $R=600\ \Omega$ $f=4\,000$ c/s	>110 dB $R=150\ \Omega$ $f=70\,000$ c/s

*) If desired these values can still be improved by using triacetyl cellulose instead of diacetyl cellulose.

**) In testing the cable one core is connected to the one electrode, all the other cores and the shielding, when present, are connected to the other electrode.

***) The cross talk damping is defined by 20 log E_1/E_2 where E_1 is the voltage which occurs at the end of that pair to whose other end a voltage is applied, and E_2 the voltage which is detected at the end of the cable on any other pair. R is the cut-off resistance of the cross, f the frequency at which the measurement is carried out.

The way in which the switchboard wire is used in shown in fig. 1 as well as *figs. 10* and *11* which show the wiring of a bay in a telephone exchange in three stages of completion. The wiring for the bays is laid out on an assembly table; the wires are joined and bound together as far as possible in bundles. This step was shown in fig. 1.

The finished bundle is now laid in the bay and

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7) If not expressly stated otherwise the values are determined after a tropics test of three days with an atmosphere of 94% relative humidity and daily temperature cycles with a maximum temperature of 45 °C.

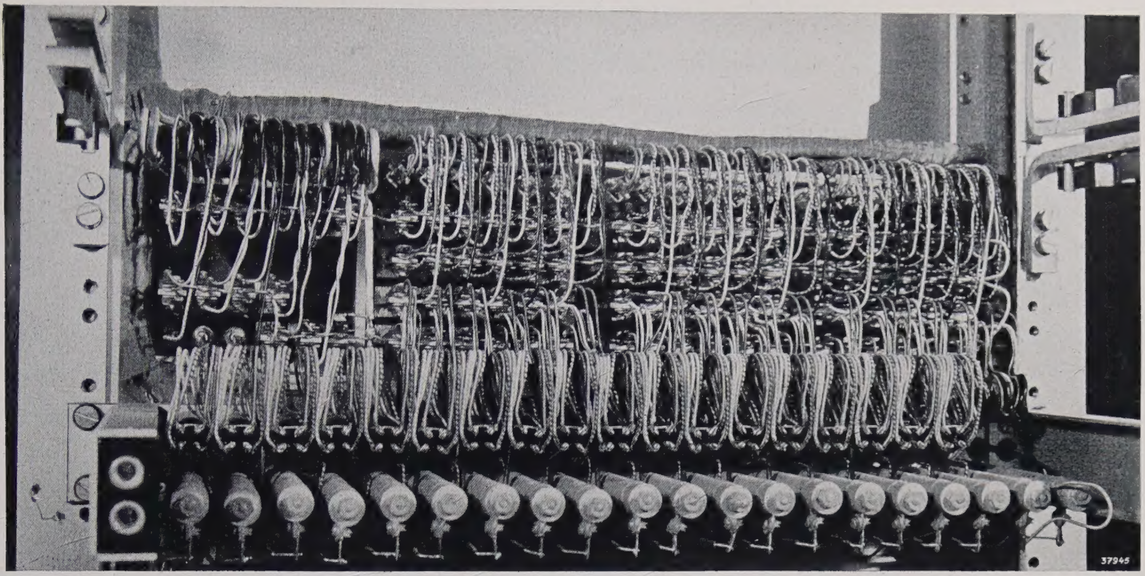

Fig. 11. Part of the wiring of the finished bay.

fastened to it, and the panels with the telephone relays, etc. are mounted. The bay assembly proper then begins (see fig. 10). In fig. 11 a part of the finished bay may be seen.

INVESTIGATION OF THE STRESSES ON PARTS OF A DIESEL ENGINE WITH THE HELP OF THE CATHODE RAY OSCILLOGRAPH

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Difficulties which arose in the case of an 8-cylinder four-stroke Diesel engine, which gives 600 h.p. at 375 r.p.m., formed the stimulus for the following investigation of stresses [1]. In this engine the bolts which fasten the cap of the main blocks of the crank shaft to the basic metal always broke.

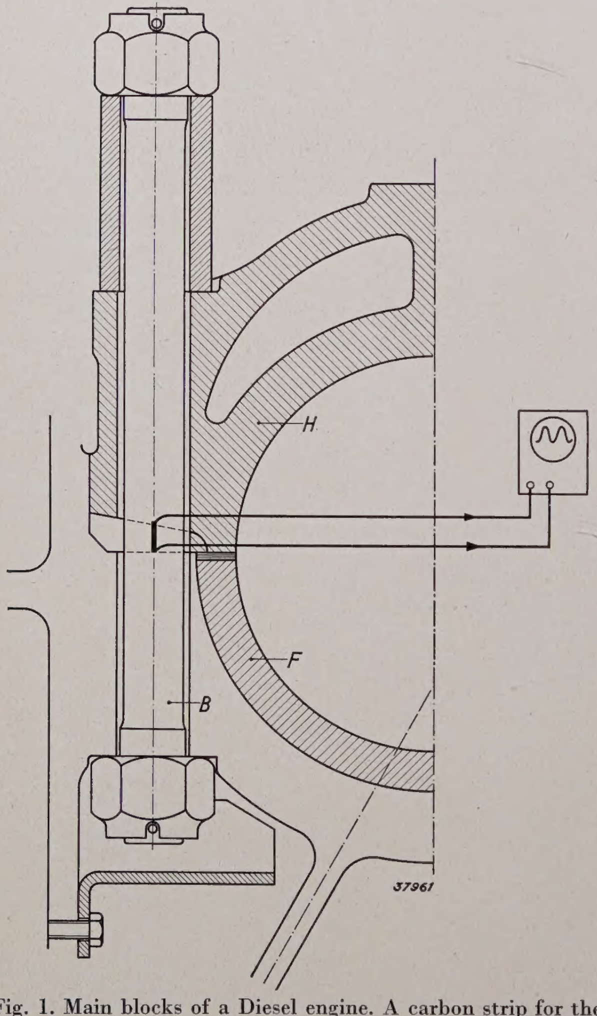

Fig. 1. Main blocks of a Diesel engine. A carbon strip for the measurement of the stress has been placed on the bolt which joins the main blocks with the engine frame.

In *fig. 1* which shows these bolts, the cap *H* of the bearings may be distinguished, the lower half *F* of the bearings, which form one piece with the frame, and one of the bolts *B* which hold the two halves together.

A possible explanation for the breaking of the bolts was that they were too much stretched at the moment when the explosion took place in the cylinder. In order to investigate this, stress measurements were made with the cathode ray oscillograph according to a method previously described in this periodical [2]. This method is based upon the fact that the resistance of a conductor which is obtained by the deposition of a layer of carbon on a strip of elastic insulation material is very much altered by a slight stretching or contraction. A strip of such a carbon layer conductor is glued to the object to be examined so that the carbon layer takes part in any stretching movements of the base. When an electric current of constant magnitude is sent through the resistance a voltage occurs between the extremities which fluctuates due to the stretch and contraction of the underlayer. These voltage variations are made visible with a cathode ray oscillograph. In order to calibrate the oscillogram obtained, the strip is previously subjected to a known stretch by means of a measuring apparatus shown in *fig. 2*.

With a four-stroke engine with 375 r.p.m. the condition in the cylinder changes periodically at a fundamental frequency of 3.1 c/s. The same fundamental frequency may be expected for the varying state of stress in the bolts. This is a much lower frequency than usually occurs in electrical phenomena, and most electrical oscillographs are unsuitable for recording phenomena of such low frequency without deformation of the oscillogram. The oscillograph GM 3 156, which was designed especially for use in tool making [3], is, however, able to do this, and was indeed used for this investigation.

In fig. 1 the main details of the arrangement may be seen. A number of bolts were provided with resistance strips in the direction of the stretch. The voltage variations occurring were fed, *via* the oscillograph amplifier, to the vertical deflection plates of the cathode ray tube. An A.C. voltage of the same frequency and phase as the motion of the piston was applied to the horizontal deflection plates.

The picture of the variation of the stretch obtained in this way was found, as was expected, to correspond in the first instance to the pressure variations in the adjacent cylinders of the engine as a function of the time. Two examples are re-

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[1] The data in this article are due to the kindness of Mr. M. J. Visser of the Department for Vibration Testing of the N.V. Werkspoor, Amsterdam.

[2] Philips techn. Rev., 5, 26, 1940.

[3] Philips techn. Rev., 5, 277, 1940.

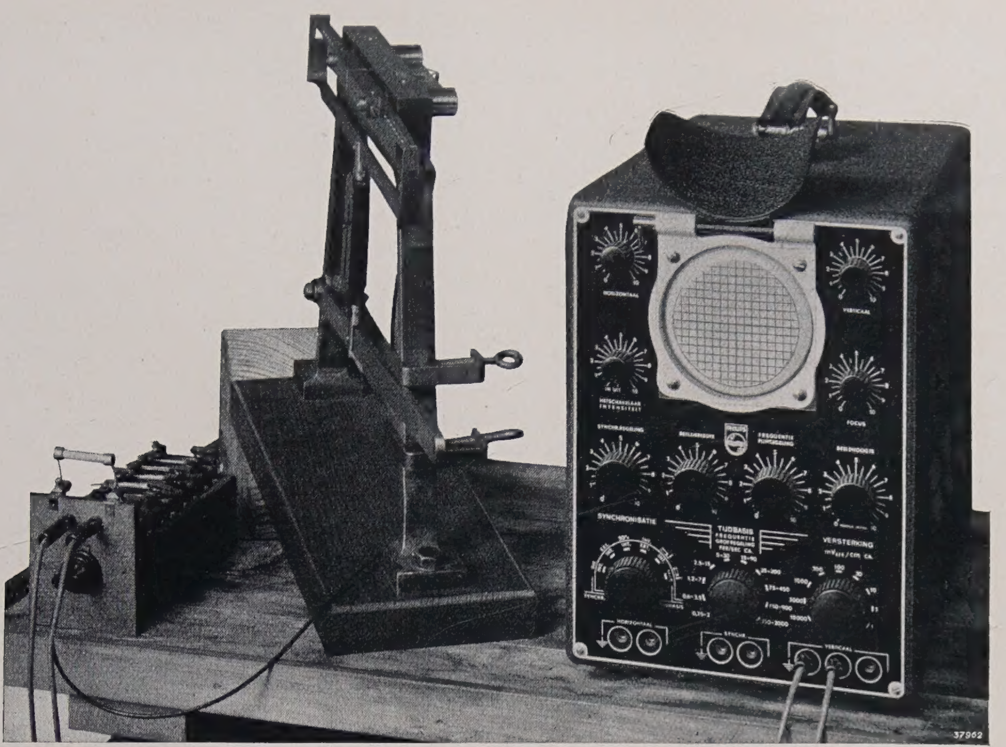

Fig. 2. Arrangement for the calibration of the resistance strips. By means of the setup shown on the left an accurately known bend is given to an elastic spring, upon which the resistance strip glued to it undergoes a known stretch. The change in resistance hereby caused is measured with a bridge connection. The oscillograph apparatus on the right serves for recording the resistance changes in dynamic stretch measurements with the help of the calibrated strip.

produced in *fig. 3*. They refer respectively to a bolt between two cylinders which move in the same rhythm and a bolt between two cylinders whose motion differs 90° in phase. The maximum stretch of the bolts calculated from these diagrams with the help of the calibration curve could in both cases be considered as permissible for the material used.

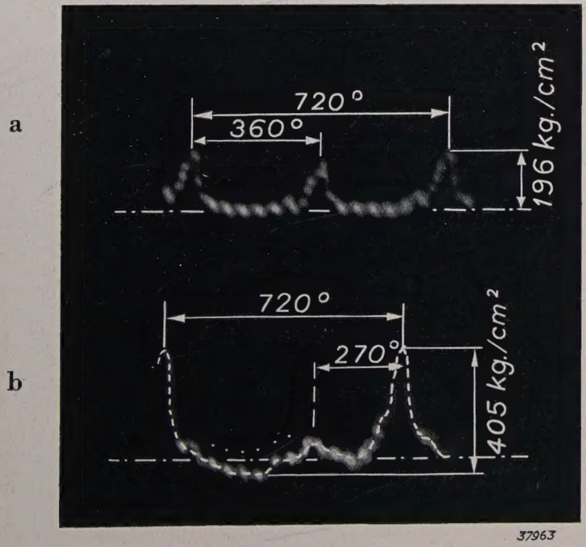

Fig. 3. Oscillograms of the tensile stresses in the bolts of a Diesel engine. *a*) Bolt between two cylinders, which move in the same rhythm; *b*) bolt between two cylinders whose motion differs in phase by 90°.

From the results of the investigation, therefore, it was found that the load on the bolts in normal use could not lead to breakage. It could be concluded from this that during the time when the difficulties were encountered the engine must have been exposed to abnormally high loads. Very probably these loads, which were superposed as extra stresses on the normal ones, loaded the bolts beyond the fatigue limit.

The engine was indeed exposed to very large and sudden changes in load. The result of these shocks was that the basic metals had obtained a certain play on the foundation plate. Because of this, lateral movements could occur upon a too sudden change in the load on the engine, which probably caused a large and irregular stress in the bolts. By a slight change in the construction the lateral motion of the basic metal could be made impossible. After that no further breakage of the bolts occurred.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIKEEN

1516: J. H. de Boer: Atomic distances in small graphite crystals and the nature of the bond (Rec. Trav. chim. Pays Bas **59,** 826-830, July-Aug. 1940).

The decrease in the distance between the carbon atoms in the atom layers of graphite crystals and the increase in the distance between these layers which Hofmann and Wilm found for small graphite particles compared with normal graphite, are an immediate result of the two kinds of binding forces which here play a part. These are the so-called homopolar bonds and the van de Waals-London attracting forces.

1517*: M. J. Druyvesteyn and F. M. Penning: Mechanism of electrical discharges in gases at low pressure (Rev. Mod. Phys. **12,** 87-174, Apr. 1940).

In this monograph a detailed survey is given of the phenomena of electrical discharges in gases at low pressures. The following subjects are dealt with: the distribution of velocity of the electrons; ionization and excitation with a small electric current through a gas; breakdown voltage and Townsend discharge (where the space charge plays practically no part); discharges in which the space charge is essentially important; the glow discharge as well as the arc in the neighbourhood of the cathode; the positive column and finally the phenomena in the neighbourhood of the anode with different forms of discharge.

1518: J. F. Schouten: The residue and the mechanism of hearing (Proc. Ned. Akad. Wet., Amsterdam **43,** 991-999, Oct. 1940).

Continuing with earlier investigations relating to subjective sound analysis and the observation of a fundamental tone which is missing in the Fourier analysis of the sound (see **1372** and **1501**; *cf.* also Philips techn. Rev. **4,** 167, 1939), this paper discusses how the perception of a complex sound may be supposed to take place in the human ear (see also Philips techn. Rev. **5,** 286, Oct. 1940). It appears to be permissible to state that the ear performs a Fourier analysis of the sound, at least in so far as its resolving power makes that possible. The earlier investigators were correct when they claimed that every periodic change in air pressure, at least within a certain interval of frequencies, will be observed as a separate tone. If it is desired simply to determine the components of a sound, it is correct to study its Fourier spectrum. If it is desired to determine the sound of every separate component, then one must not consider the frequency of the sound, but the periodicity of the wave form of the vibration by which the corresponding receiver is excited by the complex sound. This periodicity may be considerably lower than that corresponding to the characteristic frequency of the excited receiver. The pitch of the component is determined by this periodicity and not by the characteristic frequency.

1519: E. J. W. Verwey: Absolute grootte van thermodynamische grootheden voor ionen in waterige oplossing en van den electrischen potentiaalsprong aan het vrije oppervlak van water (Absolute magnitude of thermodynamic quantities for ions in aqueous solution and of the electrical potential jump at the free surface of water) Chem. Wbl. **37,** 530-535, Oct. 1940).

An estimation is given of the absolute magnitude of the reciprocal energy (change in the free chemical energy) upon the solution of monovalent ions in water. By comparison with the corresponding changes in the total free energies which can be calculated on the basis of a publication of O. Klein and E. Lange, it is found that the potential jump at the free surface between vacuum and water amounts to about —0.5 volt. This negative potential difference means that the water molecules are so arranged that an excess of water molecules have their positive poles directed toward the outside.

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*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.